DEEP-SEA RESEARCH

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DEEP-SEA RESEARCH

Editors

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I. GENERAL

1. Papers should be submitted to the Editor for the appropriate country. Papers submitted for publication will naturally be judged from the standpoint of scientific originality and novelty. Technical details of apparatus used in scientific investigation can, however, be presented in brief notes. The preparation of progress reports and review articles will be invited by the Editors from time to time and it is therefore requested that no uninvited contributions of this nature be submitted. The journal will appear quarterly, four issues making up one volume.

2. Only papers that have not been previously published will be accepted for publication in *Deep-Sea Research.*

3. Authors will receive 50 free reprints of their papers. Additional copies can be purchased if ordered at the time the first proofs are returned.

II. MANUSCRIPT REQUIREMENTS

1. Manuscripts should be typewritten. The text must be ready for printing and should be carefully checked for errors. Authors will receive proofs for correction.

2. Half-tone illustrations are to be restricted to the minimum necessary. They should accompany the manuscript mounted on separate sheets. Line drawings should include all relevant details and it is particularly requested that originals and not photo-prints should be sent. Photographs should be enlarged sufficiently to permit their clear reproduction in half-tone. If words or numbers appear in photographs, two copies are requested, one clearly printed and the other without inscription. Illustrations should be made to fit within the type area after reduction, where at all possible.

3. References to published literature should be quoted in the text as follows: SMITH (1950) – the date of publication, parentheses, following the author's name. References should be listed together at the end of each paper and not given as footnotes. They should be arranged in alphabetical order (first author's surname) to appear as follows :—

BULLARD, E. C. (1954), Heat-flow through the floor of the ocean. *Deep-Sea Res.*, **1**, 65-66.

PETTERSSON, H. and ROTSCHI, H. (1952), The nickel-content of deep-sea deposits. *Geochim. et. Cosmochim. Acta*, **2**, 81-90.

It is particularly requested that (*a*) author's initials, (*b*) title of the paper and (*c*) the volume or part numbers and page numbers are given in every case.

4. The text of articles submitted should be concise and in a readily understandable style. The essential contents of each paper should be briefly recapitulated in a summary, which will appear at the head of the paper.

5. To conserve space authors are requested to mark less important portions of their papers for printing in smaller type.

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FOREWORD

By C. D. OVEY
Secretary, Joint Commission on Oceanography, of the
International Council of Scientific Unions

IT was early in 1946, when Professor HANS PETTERSSON was planning the Swedish Deep-sea Expedition, that he was first inspired with the conception of an international body to secure co-operation in deep-sea research and co-ordination of the results. Dr. JULIAN HUXLEY, at that time Director General of UNESCO, was quick to appreciate a desire for co-operation in this field, for he realized that PETTERSSON had had the foresight to visualize that, with the invention of Dr. B. KULLENBERG's core-sampler, and the recent advances in echo-sounding devices and other techniques, great strides in investigating the deep-sea floor would, in a few years, produce important and far-reaching results, which might well revolutionize many of the theories concerning the history and development of our planet.

When PETTERSSON returned in 1948, he found that the seed of his inspiration had germinated and that, encouraged by UNESCO, the first Joint Commission on Oceanography of the International Council of Scientific Unions had been established through the International Association of Physical Oceanography, with Professor H. BOSCHMA as President and Lt. Col. R. B. SEYMOUR SEWELL as Secretary. The early days of this Commission were, however, difficult, mainly because the programme attempted was too wide; far wider indeed than that first suggested by PETTERSSON.

At the IXth Assembly of IUGG at Brussels, in 1951, a new Commission, with a programme severely limited to deep-sea research, was set up, with Dr. J. H. D. WISEMAN as President and Mr. C. D. OVEY as Secretary (see page 12 of this issue). At its first meeting at the Institut Océanographique in Monaco in September, 1952, the new Commission resolved to recommend to the International Council of Scientific Unions that a journal should be established as part of the function of the Commission in carrying out its terms of reference. This resolution was approved by the Bureau of the International Council of Scientific Unions. Subsequently, largely through the energetic action of Professor HAROLD C. UREY, an Advisory Councillor to the Commission, and of Dr. RONALD FRASER, the Pergamon Press undertook to publish this journal; thus, at least in part, realizing the dream which was Professor PETTERSSON's.

The Commission set up at Brussels stresses the fact that its work should be restricted to the investigation of the deep-sea floor. Obviously, however, as will be seen from its terms of reference set out below, this restriction still allows a wide field of scientific investigation:—

1. The morphology and stratigraphy of the deep-sea floor.
2. The general properties of the sediment carpet and its substratum.
3. The properties of the water layer next the deep-sea floor.
4. The abyssal fauna inhabiting the deep-sea floor.
5. The organisms and processes important to deep-sea sediments.

The publishers have entrusted the three editors of this first issue, who have been chosen from the Commission, to see that the subject matter of papers submitted focuses upon the deep-sea floor as the main theme; but it is emphasized that not only will basic scientific research on deep-sea problems be acceptable, but also theories and hypotheses deduced from basic work which aim at piecing together the many problems which arise in this domain, concerning the geological and climatological history of the Earth.

Department of Geography, University of Cambridge.

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International Collaboration in Deep-Sea Research

By JOHN D. H. WISEMAN

(*Received July 1953*)

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DURING September 1952 (23-25) the Joint Commission on Oceanography of the International Council of Scientific Unions held a conference in the rooms of the Institut Océanographique and the International Hydrographic Bureau, Monaco. The following members of the Commission attended the conference:- Dr. JOHN D. H. WISEMAN (President) and Mr. C. D. OVEY (Secretary), both of the British Museum (Natural History); other members: Prof. ANTON BRUUN, Zoologiske Museum, Copenhagen; Prof. LOUIS FAGE, Institut Océanographique, Paris; Prof. Ph. H. KUENEN, Geologisch Instituut, Groningen; Prof. HANS PETTERSSON, Oceanografiska Institutet, Goteborg; Prof. ROGER REVELLE, Scripps Institution of Oceanography, La Jolla, and Dr. MARY SEARS, Woods Hole Oceanographic Institution, Woods Hole. Dr. FRITZ KOCZY, Oceanografiska Institutet, Goteborg; Vice-Admiral J. D. NARES, International Hydrographic Bureau, Monaco; Commandant J. ROUCH, Institut Océanographique, Monaco, and Prof. HAROLD C. UREY, Institute for Nuclear Studies, Chicago, attended as Advisory Councillors.

In view of the complexity of the problems of deep-sea research, and the high cost of equipping and maintaining deep-sea expeditions, the main purpose of this Conference was to explore the methods of achieving greater international co-operation, so that the best scientific use could be made of existing research facilities. Opportunity was also taken of exchanging recent information on deep-sea research.

As accurate bathymetric charts of the deep-sea floor are an essential preliminary to deep-sea investigations, the Commission considered the methods whereby these charts could be improved. The first bathymetric chart was published by MAURY (1855) one hundred years ago. It was of the North Atlantic, and was based on less than 200 soundings, all taken by hemp-line. The three charts published by the late Sir JOHN MURRAY (1885) marked a real advance as they were based on all the soundings taken by the famous *Challenger* Expedition of 1873-76, as well as from other sources. These early charts were followed by others published in Germany and the United Kingdom, but there was no effective International co-operation until the VIIth International Congress of Geography at Berlin in 1899 decided to draw up a large size general bathymetric chart of the oceans. Prince ALBERT THE FIRST of Monaco undertook the preparation of this bathymetrical chart, and a plan for this was discussed by a Committee at Wiesbaden in 1903. The soundings used in the preparation of the General Bathymetric Chart of the Oceans were mainly selected from British Admiralty Charts. The work was rapidly completed and the charts were presented to the VIIIth International Geographical Congress in 1904. Work was commenced on a second edition of the General Bathymetric Chart of the Oceans in 1910 and completed in 1927. In view of the greatly increased number of soundings, which became available through the advent of echo-sounding, the Hydrographic

Conference, held at Monaco in April 1929, instructed the International Hydrographic Bureau to centralize oceanic soundings and to keep the General Bathymetric Chart of the Oceans up-to-date. Soundings for the first two editions of the General Bathymetric Chart were plotted on a relatively small scale, but for the third edition the wise decision was taken, that of plotting soundings on a scale appropriate to the degree of accuracy provided by oceanic navigational observations. The scale of the plotting-sheets used in the preparation of the third edition was 1 : 1,000,000 at the Equator, or approximately 1·88 mm per sea mile. The first sheet of the third edition (scale 1: 10,000,000 at the Equator) was published in 1935. This edition has not yet been completed, but three charts (one of the South Atlantic and two of the North Pacific) will shortly be published. Before the third edition is completed three sheets in the Southern Ocean require revision.

The necessity for up-to-date bathymetric charts was emphasized at the 1951 Brussels Assembly of the International Union of Geodesy and Geophysics, and a resolution to this effect was passed at the closing General Assembly.* The Joint Commission on Oceanography considers that accurate bathymetric charts are essential not only to a proper understanding of the deep-sea floor, but also to the earth as a whole, and that, with the passage of time, they will become increasingly important to ocean navigation. Bathymetric charts are also of use in the selection of localities where the sedimentation has been continuous and free from complications brought about by turbidity currents, as well as for geophysical and deep-sea biological investigations. The fact that bathymetric charts would have been of the greatest use during the planning and operational stages of the recent Danish Deep-sea Expedition was stressed by Dr. BRUUN, who stated that there would have been a great saving of valuable ships' time had they been available. In view of the significance of shape in the interpretation of deep-sea features, it is the Commission's view that copies of echo-profiles, together with appropriate navigational information, should be kept in a central library. In order to keep the General Bathymetric Chart of the Oceans up-to-date the Commission considers it essential that all soundings should be made available to the International Hydrographic Bureau, in such a way that they can be quickly transferred to the Bureau's plotting sheets. The Commission considers that if all the Bureau's States members co-operated with this end in view the scientific and navigational value of the General Bathymetric Charts would be greatly increased.

Concerning the representation of topographic data on bathymetric charts the Commission agreed with the recommendations of the Committee on the Nomenclature of Ocean Bottom Features (WISEMAN 1952a). It was considered that the scientific value would be greatly enhanced if each edition of the General Bathymetric Chart of the Oceans could be completed within five years and if the I.H.B. sought outside scientific advice before publication. In order to speed up publication a considerable grant in aid is essential in the Commission's view. If a five year cycle could be achieved for each new edition, and if the General Bathymetric Charts were better known to librarians and to shipping companies, it is likely that, in the course of a few years, they would become largely self-supporting. The artistic value of these charts was not commonly known.

* Report of the Ninth General Assembly of the International Union of Geodesy and Geophysics, Brussels, 21 August-1 September, 1951. *Bull. Inform. U.G.G.I., News Letter No.* 1, 1953, pp. 112-113.

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At the Monaco meeting of the Joint Commission opportunity was taken of exchanging recent scientific developments in Deep-sea research. This field is rapidly developing, and it would seem that many fundamental advances will be made during the next decade about the structure of the deep-sea floor, its geochemistry, and the origin of life. It was also considered that research in this field will influence many basic concepts in other fields of natural history.

A fundamental difficulty of deep-sea research is that it generally requires a mass of material and data which normally cannot be obtained by a single scientist or by a small group. Scientists working in this field have therefore to co-operate on both a national and international basis, in order that they have sufficient material and data collected by the most modern techniques available. Through the inventive genius of Dr. B. KULLENBERG (1947) it is now possible to obtain long undisturbed cores some 20 m in length from the deep-sea floor, and provided that these are collected in areas which have been undisturbed throughout the period of time represented by the long core, and where there have been no complications by turbidity currents, mud-slides or through the admixture of volcanic debris or by the ploughing action of holothurians, an unrivalled history of the changing conditions is left for interpretation. It may be possible, when a sufficient number of long cores have been investigated in detail, to trace accurately with time the world's past climatic changes, as well as giving some idea of the palaeocirculation both of the oceans and of the atmosphere. By investigations of this nature it may be possible to determine the causes of climatic change, as well as forecasting future changes. It is important to study, by modern techniques, the records laid down in long cores in the hope that in the future it may be possible to forecast conditions such as those which brought about the ' green years ' in Norway when corn failed to ripen (AHLMANN, 1949, p. 182). It is likely that a decrease of 2-3°C in the average summer temperature would make agriculture impossible in many marginal lands.

Work along these lines was described in a paper given at the Brussels Assembly of the International Union of Geodesy and Geophysics (WISEMAN, 1952b), and more recently a preliminary account of more detailed investigations on a short pilot-core has been published (WISEMAN, 1952c). These investigations have been carried out on very suitable cores, kindly supplied by Prof. HANS PETTERSSON. It would seem that in these cores the rate of sedimentation of the clay component has remained essentially constant with time, and there have been no complications through turbidity currents, mud-slides or through the incoming of volcanic or terrigenous débris. The deductions based on geochemical work have been supported by a statistical investigation on planktonic foraminifera (OVEY, 1950), and this work confirms the geochemical conclusion that the sea was warmer where there is a high productivity. Prof. HAROLD C. UREY (1948) has shown that the concentration of the O^{18} in calcium carbonate shells is essentially dependant on the temperature at which it was laid down, and that this can be used as a measure of past sea temperatures. At the Monaco meeting Prof. HAROLD C. UREY described this new technique, and he mentioned that measurements made on planktonic foraminifera from selected samples from a core collected in the Caribbean Sea, showed that the sea temperature was higher where there was a larger number of planktonic foraminifera and where the species distribution indicated warmer conditions. Dr. G. ARRHENIUS (1952) has carried out detailed geochemical investigations on a series of cores from the central Pacific.

Through the collaboration of Belgium and Swedish scientists it is possible that a new method for determining the rate of sedimentation based on the Ionium content of deep-sea cores will be developed (ISAAC and PICCIOTTO, 1953). This technique may possibly overcome diffusion difficulties, which would seem to influence the radium content in many long cores. Radioactive carbon measurements have recently been applied to determine the rate of sedimentation of globigerina ooze (ARRHENIUS *et al.*, 1951; KULP, J. L. *et al.*, 1952). Although it is now possible to take long cores from the deep-sea floor, there is an urgent requirement for an apparatus to take short (50-100 cm), but wide (at least 10 cm in diameter), undisturbed cores in which the topmost layer is present, as with cores of smaller diameter a considerable length is required in order to get sufficient material for C^{14} measurements. It is also desirable that a suitable technique should be developed for securing hard rock-samples, where they are exposed on the deep-sea floor. Until we have a far more detailed knowledge of deep-sea sediments our knowledge of geochemical cycles will be far from complete. This is an immense task and international co-operation is clearly called for both in the selection of areas suitable for statistical geochemical research, as well as for the standardisation of chemical methods. In view of the desirability of collecting cores in which there are no complications through turbidity currents or mud-slides, areas in which sedimentary particles have accumulated steadily, should be delineated, and their relationship to morphological features, as well as other oceanographic conditions, demonstrated. Prof. Ph. H. KUENEN (1952) has been active in drawing the attention of geologists and oceanographers to the existence of turbidity currents and mud-slides, and recently Prof. M. EWING and others (HEEZEN and EWING, 1952) have put forward arguments for the existence of turbidity currents on a large scale.

Through the collaboration of scientists, the U.S. Navy and the Coast and Geodetic Surveyors, remarkable progress has been made in recent years concerning our knowledge of submarine topographic features. Old mountains are now known in the Pacific to have remained apparently unchanged since Cretaceous times, and a deep boring has penetrated into the basement platform of Eniwetok Atoll. American submarine geologists have been largely responsible for these developments (DIETZ and MENARD 1951; MENARD and DIETZ 1951; TOLSTOY 1951; HAMILTON 1952; LUSKIN *et al.* 1952).

The rate of heat-flow through the deep-sea floor is a factor of considerable geophysical significance. A method has now been developed through the co-operation of British and American scientists whereby the rate of heat-flow can be accurately measured (REVELLE and MAXWELL 1952). Measurements made in the Pacific indicate that this rate is approximately the same as the averages for the continents. In view of the relatively high radioactivity of sialic rocks this is difficult to understand, especially if this value is found to be common for all oceans. The measurements made during the summer of 1952 by Sir EDWARD BULLARD on board *Discovery II*, in the North Eastern Atlantic Ocean, will be of great significance in resolving this problem. Many more measurements by the seismic refraction methods of the thickness of the sediment carpet on the deep-sea floor are required (GASKELL and SWALLOW 1953; OFFICER, EWING and WUENSCHEL 1952) and the gravity surveys of the ocean basins afford a most useful method of studying the substratum and should be continued at every available opportunity (BROWNE and COOPER 1950; WORZEL and EWING 1952).

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An exact knowledge of the properties of the sea-water within a few metres of the deep-sea floor will be significant in understanding the geochemistry of the oceans and the deep-sea sediments, as well as to the physical conditions under which sediments accumulate steadily. A start has been made by the Swedish Deep-sea Expedition, who investigated by special methods the vertical distribution of phosphorus, silica, oxygen, alkalinity (KOCZY 1952) and the particle content (JERLOV 1952) next to the bottom. The measurements of particle distribution show that frequently there is a stratification of particles immediately above the bottom, indicating that, whilst the turbulence is very low, eddy diffusion of the bottom currents over a rough floor is sufficient to prevent sedimentation. In other places the bottom water is entirely free from suspended matter immediately above the deep-sea floor. Many more investigations should be made, and undisturbed cores of the deep-sea floor should be taken at these localities so that the conditions governing sedimentation may be determined. Bulk samples of sea-water close to the deep-sea floor are required as it may be possible to determine the rate of circulation of the bottom water by the radioactive carbon method (KULP *et al.* 1952). It is also of interest to know whether there is any variation in the 0^{18} content of sea-water at great depths, as it may be possible from a knowledge of the 0^{18} content of benthonic foraminifera extracted from horizons in cores corresponding to glacial and interglacial periods to determine whether there were variations in the temperature of the bottom-water. This would be of importance in any reconstruction of oceanic circulation during past geological periods.

Planktonic foraminifera and coccoliths are important components of deep-sea sediments, and more information is required about their present distribution, their life-cycle, their sensitivity to sea temperature-changes, as well as the ecological factors governing their productivity. Useful work along these lines is being carried out (PHLEGER 1951) in the Scripps Institution and by Professor F. BERNARD (1949). Radiolaria have been shown to be useful indicators of derived material in deep-sea cores (RIEDEL 1952), but more information is required about their distribution and ecology.

The recent Danish *Galathea* Expedition found at least 140 species living at depths between 6,000-10,500 metres, and many more expeditions will be necessary in order to discover their distribution (BRUUN, 1951). The enlightened policy of Dr. BRUUN – the leader of the Danish Deep-sea Expedition – of having visiting specialists from many nations on board will doubtless lead to important discoveries, which would have been impossible had the expedition been run on purely national lines. For example the bacteriological investigations carried out by Prof. CLAUDE ZOBELL on samples collected from the greatest depths are giving unique results, which may prove to be of importance in understanding the origin of life. From the experience of the *Galathea* Expedition, deep-sea biological expeditions should be equipped with large trawls and other heavy gear, as the additional cost is more than outweighed by the saving of ship's time and in the abundance of animals obtained. The modern method of deep-sea trawling, developed by Dr. B. KULLENBERG (1952), worked most successfully. The food and feeding habits of animals living at great depth on or near to the deep-sea floor should be studied, and the distribution of the large holothurians is important, insofar as they disturb the stratigraphic record in deep-sea cores. Prof. LOIUS FAGE (1951) has pointed out the importance of studying at as

many localities as possible the organic carbon content of deep-sea sediments, as well as the fauna and bacteria which it supports. Such work should, of course, be accompanied by submarine photography developed with remarkable success in the U.S.A. (EWING, *et al.* 1946; EMERY 1952), and for shallower water by the Plymouth Marine Laboratory (VEVERS, 1951).

It is the view of the Joint Commission on Oceanography that many of the problems of the deep-sea are so complicated that they should not be investigated without regard to the broader problems of deep-sea research. For example the deposits collecting on the deep-sea floor are influenced by the various physical and biological processes occurring in the whole column of water. Collaboration is therefore called for, so that specialists from various nations may have the opportunity of contributing as a team towards the solution of major deep-sea problems. An admirable example of international co-operation is being made both in the U.S.A. and Scandinavia. The Scripps Institution of Oceanography organized, in co-operation with the U.S. Navy, a two ship expedition. The expedition left California in October 1952, and had on board scientists from the United Kingdom, Australia, Sweden and France. The main object was deep-sea floor investigations. In Scandinavia a Committee composed of representatives from Denmark, Norway and Sweden has been set up to organize deep-sea expeditions, and it is hoped that suitable arrangements will be made to keep the *Galathea* in commission. Preliminary plans are being made for work in the Mediterranean and possibly the Northern North Sea, where in co-operation with Icelandic Scientists it is hoped by means of the Weibull corer to use the Heckla eruptions as datable horizons in cores.

In view of recent developments in electronics, physics, chemistry, methods of detailed surveying and sampling of the deep-sea floor it is now possible to obtain a new level of understanding of deep-sea problems which will be of the greatest significance to all fields of natural science, as well as to the full economic development of the shallower seas. The Joint Commission on Oceanography, therefore, considers that the field of deep-sea research is one of the most favourable for International Collaboration in view of the great expense of equipping and maintaining deep-sea research. It is highly desirable wherever possible that scientists of different nations should participate both in planning the scientific programme and in work at sea, as well as in working up the scientific data and collections. The Commission consider that International Co-operation would be best fostered by the establishment of a Permanent Bureau, under the title of ' The International Deep-sea Council ' to act as a central organization for the following purposes:

1. To stimulate international collaboration in fundamental research in the problems of the deep-sea.
2. To act as central organization for the storage and distribution of echo-gram records.
3. To assist in the scientific preparation of Bathymetric Charts.
4. To act as the Official Body concerning the International Nomenclature of Ocean Bottom Features.
5. To publish a journal, which should become self-supporting.
6. To provide advice for the planning of expeditions.
7. To collect and disseminate information concerning new instruments and methods.

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8. For such other purposes as may arise from time to time.

It is the Commission's intention to investigate the possibilities of a Permanent non-governmental Bureau, as well as the sources of financial support.

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Definitions of Features on the Deep-Sea Floor

By JOHN D. H. WISEMAN and CAMERON D. OVEY

(*Received June 1953*)

Summary—The work of the International Committee on the Nomenclature of Ocean Bottom Features, and that of various national groups, is described. A list of approved terms of deep-sea features and their definitions is given. In order to avoid confusion, it is hoped that these terms will be used as widely as possible.

INTRODUCTION

AT the VIIIth Assembly of the International Union of Geodesy and Geophysics at Oslo in 1948, the Association of Physical Oceanography established an international committee, under the chairmanship of J. D. H. WISEMAN, to define as concisely as possible morphological features of the deep-sea floor. It was thought necessary and timely that an international standard of nomenclature should be clearly stated in view of the rapid evolution of deep-sea research resulting from recent developments in practical methods of sounding and of obtaining long cores of the floor, and of geophysical advances in studying the morphological disposition and constitution of rock-layers and geological features at depth. J. D. NARES, formerly the Director of the International Hydrographic Bureau, agreed to act as Secretary and other members were K. O. EMERY (U.S.A.), H. H. HESS (U.S.A.), Ph. H. KUENEN (Holland) and HANS PETTERSSON (Sweden).

THE BRITISH NATIONAL COMMITTEE

A British National Committee was established with the following members:– J. N. CARRUTHERS* (Hydrographic Department of the Admiralty), L. H. N. COOPER (Plymouth Marine Biological Laboratory), H. F. P. HERDMAN) *Discovery* Committee)†, W. B. R. KING (Professor of Geology, Cambridge), R. B. SEYMOUR SEWELL (Department of Zoology, Cambridge), J. A. STEERS (Professor of Geography, Cambridge), J. D. H. WISEMAN (Chairman; British Museum (Natural History)) and C. D. OVEY (Secretary; British Museum (Natural History)).‡

The first meeting was held in the Board Room of the British Museum (Natural History) on 28 January 1949, by kind permission of the Director and Trustees but, by the end of the year, the newly established British National Committee on the Nomenclature of Ocean Bottom Features became a sub-committee of the Royal Society Oceanography Sub-committee of the National Committee of Geodesy and Geophysics.

* On being transfered to the National Institute of Oceanography, DR. CARRUTHERS was replaced on the Committee by Commander G. S. RITCHIE.

† The *Discovery* Committee has now been incorporated as part of the National Institute of Oceanography.

‡ Appointed to the Department of Geography, Cambridge, as from 1 October, 1953.

Many documents and two reports have been issued by the British Committee. These have been circulated to the members of the International Committee and to other groups and individual scientists with a request for constructive criticisms. It was the policy of the British Committee to welcome constructive criticism because no satisfactory solution to the problems of deep-sea nomenclature could be found unless there was a free interchange of ideas.

PRELIMINARY WORK OF THE BRITISH COMMITTEE

The Committee began its work by considering the physiographical features of the deep-sea floor as listed and defined by G. W. L. LITTLEHALES in " The Configuration of the Ocean Basins " (1932), and the preliminary findings were presented to the International Committee at Brussels during the IXth Assembly of the International Union of Geodesy and Geophysics in 1951 (see below).

Much revision of LITTLEHALES' definitions was found necessary. Some of his little-used terms have been omitted whilst others have been added for newly discovered features. No attempt has been made to define continental-shelf features, apart from ' Submarine Canyon,' as the work of the Committee is primarily concerned with those features found in open oceans.

Owing to the limited knowledge of the origin of oceanic features, the Committee considered it desirable, as a general principle, to avoid implications in the definitions about origin. In addition it was felt that the definitions should be brief, readily translatable into languages of maritime nations and, in consequence, lengthy explanations have been avoided.

MEETING OF THE INTERNATIONAL COMMITTEE AT BRUSSELS, 1951

At the IXtn Assembly of the International Union of Geodesy and Geophysics in August 1951, the International Committee gave consideration to the work of the British National Committee. At this Assembly two meetings were held. Unfortunately both H. H. HESS and K. O. EMERY were unable to leave the U.S.A., but their representatives, G. LIEFSON (U.S. Navy Hydrographic Department) and R. DIETZ (U.S. Navy Electronics Laboratory, San Diego) were present.

With the object of consolidating national opinion the committee proposed that national groups should be established. Unfortunately both in Holland and in Scandinavia this was not possible. In the U.S.A. a loosely co-ordinated group, consisting of H. H. HESS, K. O. EMERY, F. P. SHEPARD, R. DIETZ, R. H. FLEMING and the Directors of the U.S. Coast and Geodetic Survey, had been already established.

In the British Committee's Report to the International Committee, definitions were given to the terms which were considered necessary for the description of submarine topography. The International Committee noted with great satisfaction that there was, in general, agreement about the definitions among those whom the British Committee had consulted in other nations, but it considered that a few of these terms required improvement (WISEMAN, 1952, p. 71).

MEETING OF THE INTERNATIONAL COMMITTEE AT MONACO, 1952

After the British National Committee in consultation with other national groups

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had reconsidered the definitions laid before the International Committee in August 1951, the final form of the definitions was drafted at Monaco by the International Committee. The meeting was held in the International Hydrographic Bureau by kind permission of the Directors immediately preceding the meeting of the Joint Commission on Oceanography. C. D. OVEY, Secretary of the British Committee, was elected Joint-Secretary of the International Committee with J. D. NARES. H. H. HESS and K. O. EMERY were again unable to be present but were represented by MARY SEARS and R. REVELLE. Others co-opted were H. L. BENCKER, F. KOCZY and A. VIGLIERI.

The minutes of this meeting were circulated and later confirmed by post and the whole will be printed in due course by the International Hydrographic Bureau.

FINAL AGREED PRINCIPLES GOVERNING NOMENCLATURE

A. *Selection of new terms*

(a) *For major features*

(1) Terms should be simple, unambiguous and, if possible, descriptive. This not only facilitates scientific discussion, but would encourage mariners to investigate deep-sea topography.

(2) As knowledge of deep-sea topography is rapidly expanding terms which imply origin should not be used, because even the best genetical theories frequently change with time.

(3) Terms, which have a confusing double meaning, should be avoided.

(4) Terms should, if possible, be readily translatable into the languages of maritime nations.

(5) It is desirable for any author or chart-making authority, before proposing a new term for an oceanic feature outside the 100-fathom or 200-metre line, first to consult a national group.

(b) *For secondary features*

(1) The general principles given in para (a) should apply.

(2) The International Committee considers that there is an undoubted case for the systematic development of a new terminology for secondary features, and recommends that a start should be made for those off Southern California. A group of Californian Submarine Geologists will look into this question.

B. *Definitions*

(1) All definitions should be brief, simple and unambiguous.

(2) Although implications about origin should be avoided, the aim of definitions should be to facilitate genetical discussions.

(3) In any one definition no previously undefined term should be used.

(4) They should be readily translatable into the languages of maritime nations.

FINAL AGREED DEFINITIONS

1. *Continental Shelf, Shelf Edge and Borderland*
The zone around the continent, extending from the low-water line to the depth at which there is a marked increase of slope to greater depth. Where this increase occurs the term shelf edge is appropriate. Conventionally its edge is taken at 100 fathoms (or 200 metres) but instances are known where the increase of slope occurs at more than 200 or less than 65 fathoms. When the zone below the low water line is highly irregular, and includes depths well in excess of those typical of continental shelves, the term Continental Borderland is appropriate.

2. *Continental Slope*
The declivity from the outer edge of the continental shelf or continental borderland into great depths.

3. *Borderland Slope*
The declivity which marks the landward margin of the continental borderland.

4. *Continental Terrace*
The zone around the continents, extending from low-water line, to the base of the continental slope.

5. *Island Shelf*
The zone around an island or island group, extending from the low-water line to the depths at which there is a marked increase of slope to greater depths. Conventionally its edge is taken at 100 fathoms (or 200 metres).

6. *Island Slope*
The declivity from the outer edge of an island shelf into great depths.

7. *Basin*
A depression of the deep-sea floor more or less equidimensional in form, but not necessarily large and pronounced.

8. *Trench*
A long but narrow depression of the deep-sea floor having relatively steep sides.

9. *Submarine Canyon and Valley*
An elongated steep-walled cleft running across or partially across the continental shelf, the continental borderland and/or slope, the bottom of which grades continually downwards. When the sides have a more gentle slope the term submarine valley is more appropriate.

10. *Depth*
A term which may be used for a few of the deepest soundings.

11. *Deep*
The well-defined deepest area of a depression of the deep-sea floor conventionally applied where soundings definitely exceed 3,000 fathoms.

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12. *Rise*
A long and broad elevation of the deep-sea floor which rises gently and smoothly.

13. *Ridge*
A long elevation of the deep-sea floor having steeper sides and less regular topography than a rise.

14. *Seascarp*
An elongated and comparatively steep slope of the sea floor.

15. *Gap*
A steep-sided furrow which cuts transversely across a ridge or rise.

16. *Sill and Sill Depth*
A submarine ridge or rise separating partially closed basins from one another or from the adjacent Ocean. The greatest depth over the sill is commonly known as the sill depth.

17. *Plateau*
A very extensive but ill-defined elevation of the deep-sea floor, the top of which may be diversified by lesser features of elevation and depression.

18. *Seahigh*
An elevation of the deep-sea floor of approximately 3,000 feet or more, the morphology of which is insufficiently well known to be covered by a more precise definition.

19. *Seamount*
An isolated or comparatively isolated elevation of the deep-sea floor of approximately 3,000 feet or more.

20. *Tablemount (or Guyot) and Oceanic Bank*
A seamount (roughly circular or elliptical in plan) generally deeper than 100 fathoms, the top of which is a comparatively smooth platform. When the platform has a depth of less than 100 fathoms the term oceanic bank is appropriate.

21. *Seapeak*
A seamount (roughly circular or elliptical in plan) with a pointed top.

22. *Seaknoll*
A submarine hill or elevation of the deep-sea floor less prominent than seamount. (This term should only be used if the feature has been adequately surveyed, and the terms seamount, tablemount or guyot, and seapeak should be used if the elevation exceeds approximately 3,000 feet, above the surrounding floor.)

23. *Deep-sea Terrace*
A bench-like feature bordering an elevation of the deep-sea floor at depths generally greater than 300 fathoms.

NAMING OF DEEP-SEA FEATURES

The British Committee is at present revising the names of deep-sea features in the

light of modern requirements. The International Committee have asked the British Committee to publish their proposed names of features in the different oceans, so that these can receive wide publicity before decisions are taken by the International Committee.

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The Swedish Deep-Sea Expedition, 1947-48

HANS PETTERSSON*

(*Received May 1953*)

ALTHOUGH Sweden has been active in oceanography for nearly a century, Swedish efforts were mainly concentrated within Scandinavian waters and to the relatively moderate depths there met with. Nevertheless, these studies led to an international co-operation – the International Council for Sea investigations set up at the beginning of this century on Swedish initiative (OTTO PETTERSSON *et. al.*). With the outbreak of the Second World War Swedish activities at sea were severely limited, mainly to the fjords and the territorial waters immediately outside these.

On the other hand, thanks largely to the munificience of private donors, in Göteborg, and in Stockholm, Swedish oceanographers in the decade preceding the war had been provided with excellent institutions and other resources for laboratory work in the science of the sea, like Bornö Station on the Gullmarfjord, already founded in 1902 as a privately-owned research station, but acquired by the Swedish Government thanks to private donations in 1935, the Oceanografiska Institute in Göteborg bequeathed to the Royal Society in Göteborg by the Wallenberg Foundation and inaugurated in the beginning of 1939. Moreover, in 1930 a chair in oceanography had been founded at the University of Göteborg by private donors.

With these resources Swedish oceanographers, during the enforced inactivity of the Second World War, seized the opportunity for constructing and testing new instruments and other implements of deep-sea research and for planning a circumnavigating deep-sea cruise, from which the new technique was to be utilized, as soon as the cessation of hostilities at sea permitted. In 1946 the Government research vessel, the *Skagerak*, was put at our disposal for a test cruise of 2½ months duration to the Western Mediterranian, during which the new equipment was to be tried out in depths considerably greater than those accessible within Scandinavian waters (PETTERSSON 1947a). Besides the Swedish technique we also had on board the *Skagerak* a new recording echograph for great depths, constructed for us by the well-known London firm, Henry Hughes & Son (Marine Instruments Co.). The results from this experimental cruise gave excellent promise for the coming enterprise in the open oceans, and at the same time gave valuable information for various reconstructions, increasing the efficiency and the reliability of the new gear.

The great problem of obtaining a research ship of the capacity necessary for a deep-sea cruise of 15 months was solved, thanks to the generosity of a Swedish shipping concern, Broström & Co., in Göteborg, in giving us the loan of their new training ship, the 1,450 tons motor-schooner *Albatross*, and at the same time giving us permission to establish in the holds and other cargo-space of the ship our laboratories and accommodation for a scientific staff of 10 to 12, all air-conditioned for work in the tropics.

* cf. H. PETTERSSON : " A Swedish Deep-Sea Expedition." *Proc. Roy. Soc.*, B, **134**, 400 (1947).

The very large sums required for running the ship were given by generous donors in Göteborg. Thanks to this munificience the very high cost of the whole enterprise could be defrayed entirely from private donations, relieving us of the necessity of applying for any government grant which, at that time, it would have been most difficult to obtain.

With a picked staff and crew on board, the *Albatross* set out from Göteborg on 4th July 1947 with a 15 months leave of absence (which we actually did not exceed) returning to Goteborg on 3rd October 1948. The whole course followed is set out in Fig. 1 and the ship *Albatross* under sail is shown in Fig. 2.

The ship was ably commanded by Captain N. KRAFFT. Twelve young apprentices belonged to the crew and did their share of the work with a will.

The cruise had been planned to work chiefly in great ocean depths of 4,000 metres and more, the greatest part of the efforts being devoted to the deep-sea sediments from which cores of great length were to be raised. For this purpose we had on board the excellent core-sampler of the piston-type, constructed by Dr. B. KULLENBERG (1947) to whose work on board goes the credit for raising the long cores, up to nearly 20 metres in length, as compared with an earlier maximum length of 3 metres. An electric deep-sea winch of special construction, made by the Swedish firm, " Asea," made it possible to lower such a long core sampler through depths exceeding 5,000 metres (the record depth from which a long core was taken being 7,500 metres) in the course of only 3 to 4 hours.

For the handling of these very long and heavy cores it was essential to work in good weather with a minimum of wind and ocean-swell. For this reason our cruise was planned to operate within or near the zone of equatorial calms. This programme, at the same time, afforded us means for criss-crossing the equatorial current-system, allowing our oceanographers opportunities for studying the dynamics of the equatorial countercurrent and also to obtain cores from the sediments on the bottom accumulated below zones of " convergence " and " divergence ". (JERLOV *et. al.*).

Thanks to the excellent echograph already mentioned, we were able, under favourable conditions of wind and swell, to obtain continuous records of the bottom profile even down to depths exceeding 7,000 metres. The results, which are soon to be published, proved the astonishing fact that the bottom profile is, in general, distinctly rugged also in very great depths and that flat areas, where the depth is constant, or nearly so, are rather the exception than the rule. This fact, unknown before the *Albatross* Expedition, obviously raises important questions regarding the dynamics – tectonic and volcanic – of the deep-sea floor. It would have seemed reasonable to assume that the sedimentation going on uninterruptedly for hundreds of millions of years, would have had time to smooth out a primary ruggedness of the rocky substratum, whereas our results seem to imply, that a *resculpturing* of the deep-sea floor goes on, producing and maintaining more or less abrupt differences in level.

However, apart from its theoretical aspects, the ruggedness of the deep-sea floor considerably complicated and hampered the investigations made, both by means of the long coring-tubes and by means of the trawl and the dredge for studying the abyssal fauna. In addition to these we also used a technique due to the Swedish scientist Prof. W. WEIBULL for measuring the thickness of the sediment layer (WEIBULL 1953), at that time practically unknown in great depths, down to the underlying substratum, by means of recording the echoes from depth-charges exploding

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in great depths, a kind of " echo-sounding " of the sediment layers themselves. This technique obviously requires a smooth bottom, or spurious echoes thrown back by rocks or ridges on the ocean floor will inevitably obscure records from sub-sedimentary echoes. (Prof. WEIBULL's paper is being printed in our reports).

A special technique developed before and during the cruise by Dr. N. G. JERLOV 1953 aimed at studying the optical properties of sea water, especially at great depths, and also the prevalence of suspended particles and their stratifications as " clouds " in intermediate water layers. These measurements incidentally gave a first knowledge of the movements of the bottom water, otherwise inaccessible to direct observation by current meters, and also information on the highly important movements to the vertical direction within regions of " convergence " and " divergence " nearer to the surface. Finally Dr. F. KOCZY (1950) developed a novel method for taking undisturbed water samples quite near the bottom as well as in different well-defined heights above the same.

A salient feature in our programme was the sampling and conservation of large quantities of the sea water from different depths in order to measure the quantity of uranium and radium present in the water. Earlier work in Göteborg and elsewhere had indicated the possibility of utilizing radioactive age-determinations in the sediments, and in the concretions in great depths as a means for determining their, practically unknown, rate of growth (PETTERSSON 1949).

Finally, biological investigations in great depths by means of the trawl in order to study the abyssal fauna were also included in the programme. For various technical and other reasons this work, led by Prof. O. NYBELIN of Göteborg, had to be limited to the last 3½ months of the cruise within the North Atlantic Ocean (NYBELIN *et al.* 1951)

When the *Albatross* returned to Göteborg on 3rd October, 1948, she carried in a special cold-storage room over 200 sediment cores from great depths with an integral length of about 1,600 metres. By means of a special packing technique they had been preserved from mechanical damage and from dessication and they were, on landing, transferred into a special cold storage room within the Oceanographic Institute of Goteborg. Practically all the resources of this institute were reserved for the working up of the sediment cores and other samples. Many samples have been distributed to different specialists in other laboratories who are shouldering the many problems involved. Work on the many samples, which is still proceeding, is due to the wholehearted co-operation between eminent specialists in other institutions, in Sweden and abroad, to whom we are greatly indebted.

Thanks to generous grants from the Swedish Research Council and from various private donors in Sweden it has been possible to finance this extensive co-operation, and a special grant from the Swedish Government enables us to publish the results, as they are worked out, in the " Reports of the Swedish Deep-Sea Expedition."

The following, necessarily very brief summary, gives the main results hitherto obtained, some of which are still in the press. In order to make our results and our technique accessible to workers in other institutions and countries, it was planned to bring out the Reports complete with a 5-year period. This has not proved possible, but we have reasonable hopes that in another two or, perhaps, three years from now, i.e. before the end of 1956, within a decade from the start of the cruise, the essential parts of the report will have been published.

A. The bottom configuration of the deep-sea, according to the echograms taken along the course of the *Albatross*, afford a very considerable interest for the reason already stated – the surprising ruggedness of the deep-sea floor. The echograms, now being worked up for publication by Dr. F. KOCZY, will afford a first opportunity for the study of the " micro-structure " of the ocean bed.

B. Through mineralogical studies a new and interesting light has been thrown on the origin of the coarser mineral fragments of the sediments in great depths. It appears that these are largely due to a "mylonization," a crushing effect of the basic rocks probably due to differential movements of the same.

C. Other mineralogical studies have proved submarine " weathering," with a chemical metamorphosis of gravel and stones on the bottom through their interaction with the surrounding water to be an important feature in the production of deep-sea sediments.

D. The occurrence, even in mid-ocean waters, of deep-sea sand of a different character, i.e. not of basaltic or ultrabasaltic origin suggesting a local transport by horizontal currents, in certain cases possibly by " turbidity " currents.

E. Chemical interaction between sediment and bottom water specially studied by KOCZY, seem to bear out the view, earlier stated by the present author, that chemical effects from acids of magmatic origin may play an important part in deep-sea chemistry, especially at the origin of red clay. Incidentally, KOCZY's investigations have proved that eddy-diffusion near the bottom may be reduced to one-thousandth part or less of its value in the higher water strata.

F. Both JERLOV's particle studies and the study of the microfossils in the sediment by W. RIEDEL (1952), and G. ARRHENIUS *et al.* (1952) strongly support the view that erosion by bottom currents may displace sediment layers already settled on to the bottom, and may be responsible for certain local occurrences of pre-quaternary bottom sediments in or near the sediment surface.

G. The study of the long cores themselves, sampled at frequent intervals, generally for each 10 cm, has been most revealing regarding the process of sedimentation. Especially near the Equator, and there, preferably, below the bands of divergence and convergence, there is often a pronounced stratification, layers rich in lime, largely foraminifera shells, alternating with layers poor in lime. On the other hand, within certain regions where the bottom is covered with nearly lime-free red clay or with radiolarian ooze, the sediments may be nearly homogenous down to depths of at least 15 metres below the sediment surface. Considering that in these regions the rate of sedimentation is very low, such a length of core may correspond to a time-span of 15, or even of 30 million years, proving that red clay *was being formed as early as in the Tertiary Age.*

H. The study of the microfossils in the deep-sea cores at different levels, especially of foraminifera-shells and of radiolarians and diatoms, has thrown light on changes in the past, both of the conditions of sedimentation and has revealed changes in the surface water temperature, i.e. paleoclimatic changes. Such studies have been carried out especially by F. PHILEGER and his co-workers

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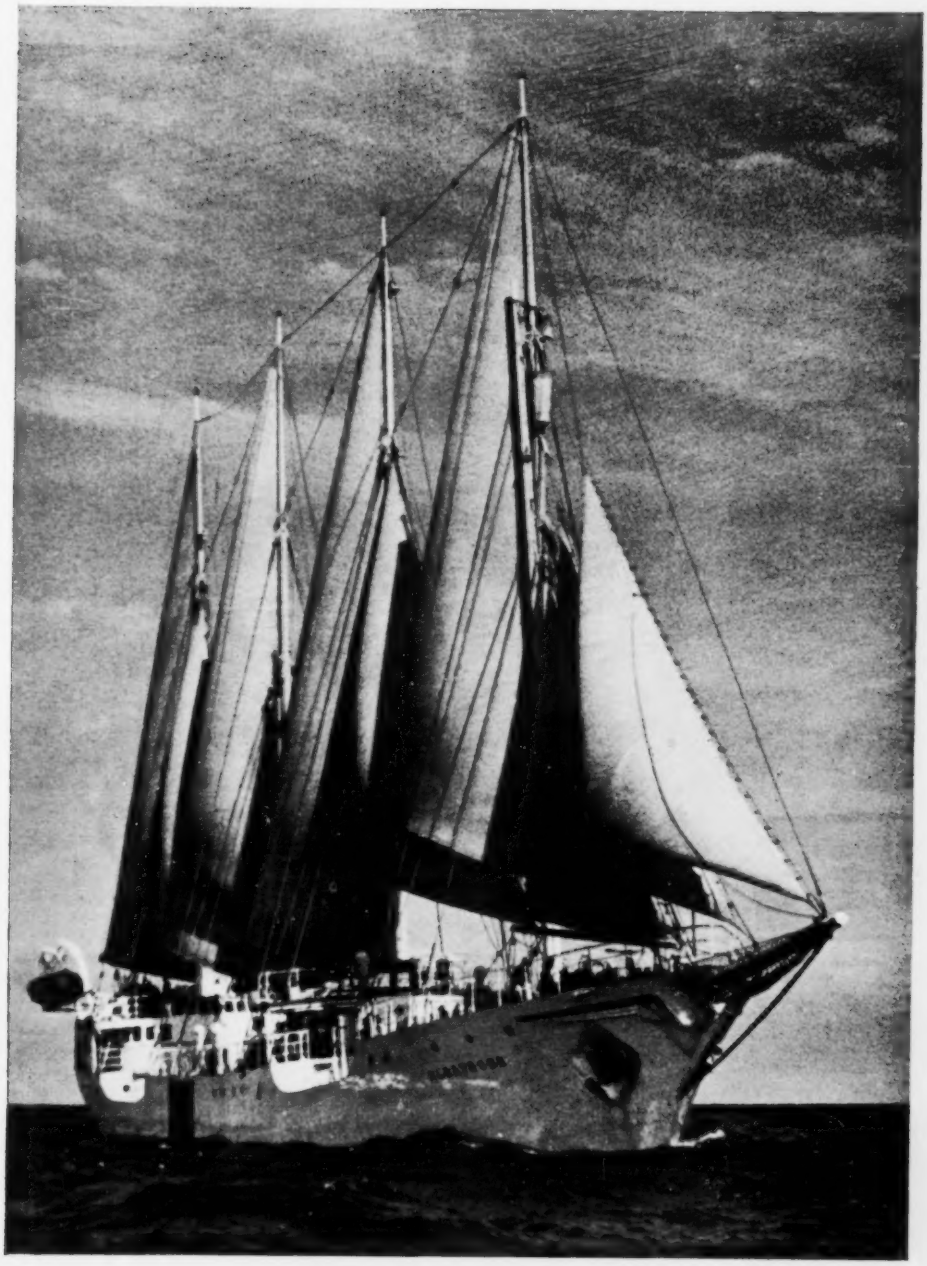

Fig. 2. The *Albatross* under sail

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(1953) in the Scripps Institute, by W. SCHOTT (1952) in Hannover, and W. RIEDEL (1952) in Göteborg, by OVEY and WISEMAN in London, by KOLBE, BROTZEN and ARRHENIUS in Stockholm and in Kagghamra (1952). At present the study of the foraminifera-shells and the frequency-variations in their different species afford one of the most promising ways to establish a submarine chronology, at least tentatively.

I. Studies of the minerals and of the granulometric structure of cores, especially from the Mediterranean and from the North Atlantic, by NORIN in Uppsala and by MELLIS in Stockholm, have given important results both as to the formation *in situ* of certain new minerals and as to the occurrence of volcanic ash, which can be linked up with early historic and prehistoric volcanic eruptions.

J. Quantitives studies of the chemical elements present in deep-sea sediments made by S. LANDERGREN in Stockholm with spectrographical methods, by G. ARRHENIUS in Kagghamra with chemical, partly spectrographic methods, and by ROTSCHI and BERRIT in Göteborg with microchemical methods (mainly concentrating on the ferrides) have given important clues to the genesis of deep-sea sediments. The relatively high percentage of nickel in the sediments of the lowest rate of sedimentation may possibly indicate a contribution of cosmic nickel from meteorites or from meteoric dust.

K. Investigations on the occurrence of uranium, radium, thorium in deep-sea sediments, especially in red clay from the Central Pacific Ocean, mainly carried out in Göteborg by PETTERSSON, BERNERT, KRÖLL *et al.*, and in Vienna by G. KOCZY, have confirmed earlier results gained in Sweden regarding the practical constancy of the uranium content (according to BERTA KARLIK $1{\cdot}3 \cdot 10^{-9}$ g U/cc of ocean water), the relative scarcity of radium, $\sim 10^{-16}$ g Ra/cc which is only a fraction of the amount in equilibrium with the dissolved uranium. In order to explain the high radium content in the sediment surface and its scarity in ocean waters PETTERSSON (1937) has suggested that the ionium produced from uranium becomes precipitated on to the sea-bottom and there, in the course of time, gives rise to " ionium-supported " radium. In the simplest case this should lead to a vertical distribution of the two elements with the downwards decline regulated by the disintegration of ionium, in which case age-determinations in the upper sediment layers could be based on radium measurements. However, a much more complicated distribution of the radium to the vertical direction (KRÖLL 1953), has led to the suspicion that radium migrates within the sediment column from its mother element and hence cannot be used as a direct measure of age. In order to overcome this difficulty, E. PICCIOTTO and N. ISAAC in Brussels (ISAAC and PICCIOTTO 1953) have developed a photographic method, counting under the microscope the number of α-tracks from a fraction of a sediment sample, containing only the thorium-isotopes. From these counts the quantity present, not only of ionium but also of thorium, can be found. The results so far gained by this new and very laborious method are promising. They seem to confirm the general correctness of the ionium-precipitation hypotheseis and also the assumption that radium has a tendency to migrate in the sediment column.

L. The rate of sedimentation found, either from investigations of the microfossils in the sediment or from radioactive measurements show that a normal rate of sedimentation in true oceanic sediments varies from a minimum in the Pacific red clay of about 1 mm (or less) in 1,000 years to a maximum in calcareous ooze of between 15 and 25 mm in 1,000 years. In more continental seas such as the Mediterranean the rate of sedimentation may rise locally to values of 100 mm in 1,000 years or even more. This problem, however, calls for further and more extensive investigation. In his important thesis on cores from the East Pacific G. ARRHENIUS (1952) has assumed the rate of sedimentation of titanium to be the least variable in mid-oceanic water and has based his calculations of the "titanium-age" on the concentration of the element present in different layers of a long core, combined with measurements of radiocarbon near the sediment surface. Some other authors are more sceptical regarding this assumption of titanium as a dependable measure of submarine geochronology, especially as to the question whether the present values for titanium sedimentation have remained unchanged over a very long span of time.

M. The biological studies carried out during the final Atlantic cruise of the *Albatross* thanks largely to KULLENBERG's studies of the cable length, were eminently successful and gave a rich harvest of rare deep-sea organisms (NYBELIN and KULLENBERG 1951). The deepest haul, made to the north of the Virgin Islands, gave unmistakable proof that, even at depths as great as 7,600 metres, bottom-living organisms exist, an increase in depth over the Prince of Monaco's record from the beginning of the century by nearly 1,600 metres. The Danish Deep-Sea Expedition with the *Galathea* in 1950-51, profiting from the experiences gained from the *Albatross* and using its excellent deep-sea winch, has pushed the record depth down still further, in the Philippine trench, where living organisms were collected from the immense depth of 10,400 metres.

N. The results from WEIBULL's depth-charge method of sounding the sediment thickness gave maximum values of 3,500 metres in the eastern Atlantic Valley between Madeira and the Central Atlantic Ridge, whereas neither in the open Pacific Ocean nor in the Indian Ocean reflecting surfaces were discovered in greater depths than a few hundred metres; these low values have later been confirmed by American and British expeditions. It is possible that this result may be due to the intervention of deep-lying lava-layers below superficial sediment beds of moderate thickness intercepting echoes, thrown back against still deeper reflecting surfaces. Otherwise they would lead to values for the total thickness of deep-sea sediments much lower than those estimated by KUENEN, some 3,000 metres as an average thickness of deep-sea sediments.

O. During the *Albatross* expedition the first attempts to measure the temperature gradient in deep-sea sediments were made by means of geothermometer of special construction. At the lower end of a steelt ube, 11 meters long, a highly-sensitive alcohol thermometer, hermetically protected against the external water-pressure, was included, sensitive to about 0·007 Centigrade. Lowered into the isothermal bottom water until the surrounding water temperature had been attained by the geothermometer, it was then plunged into the sediment

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until the temperature-sensitive lower end was in a depth of 11 metres and then left there to assume the temperature of the surrounding sediment. By means of a clockwork, stopcocks were turned at predetermined intervals of time, thus immobilizing the alcohol in the index tubes, one giving the temperature of the bottom water, the other that of the sediment 11 metres below the bottom.

Through a faulty construction the clockwork repeatedly failed to work in the ice-cold bottom water, so that only three values of the temperature gradient were obtained, one in the central Pacific Ocean, close to the Equator, in a depth of about 4,400 metres, where the temperature was found to rise in the sediment by 1° in about 21 metres, one in the Western Pacific Ocean in a depth of 5,300 metres with a rise of 1° in 26 metres, and one in the Indian Ocean between the Cocos Islands and Christmas Island, where a much steeper gradient was found, viz. 1° in about 4 metres. Even the low conductivity found in deep-sea sediments these gradients, in the two first-named cases, give a geothermal current comparable in intensity with that found on an average in the continents. The third, higher value, is more comparable with those gradients found near volcanoes or solfataras.

More recent experiments carried out by American expeditions have in general confirmed these unexpected results (REVELLE *et al.* 1952-53).

P. Even before the *Albatross* cruise was started, the present author had arrived at the conclusion that the current explanation of the solution of lime from the red clay, viz. by cold water moving along the bottom by Arctic, and especially Antarctic, bottom currents, could *not* be the correct explanation. It would *inter alia* lead to the conclusion that during the uniformly warm Tertiary Age, when polar ice caps, affording the low temperature and the motive power for the ice-cold currents from higher latitudes, should have been missing, no red clay was formed. The definitive negation of this assumption was brought through the long red-clay cores raised from the *Albatross* both in the Atlantic and the Pacific Oceans. An altogether independent confirmation of this view has been brought recently by EMILIANI and EDWARDS, who have been using the wonderful method due to HAROLD UREY in Chicago, of measuring the proportion between the light and the heavy oxygen isotopes as indicators of pale climatological data. Applying this method to foram shells of Tertiary Age, raised from great depths in the Eastern Pacific, EMILIANI and EDWARDS (1953) in great depths have found temperature values varying between 9°·4 and 11°·5, i.e. about 8° Centrigrade higher than during present post-glacial conditions.

It seems obvious, therefore, that cold bottom currents are not an essential condition for the conversion of calcareous ooze into red clay. It seems to the present author much more plausible that it is the action of magmatic volatiles, carbon dioxide and hydrochloric acid which have been responsible for a world-wide production of red clay and other lime-free or nearly lime-free sediments.

Göttenborg, Sweden

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Trans-Atlantic Profile of Total Magnetic Intensity and Topography, Dakar to Barbados

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(Lamont Geological Observatory Contribution No. 91)

(*Received May* 1953)

Summary—The development of the airborne magnetometer makes possible magnetic surveys of ocean areas without specially constructed non-magnetic ships. Early flights over marine areas indicated that a correlation might exist between topographic features and the character of the magnetic field. In order to compare magnetic field characteristics with topography and basement structure as determined by seismic measurements an airborne instrument was incased in a waterproof " fish " and initially towed from the *Atlantis* in 1948. Until an adequate cable was obtained in 1952 repeated failures of the electrical cable had limited the instrument's use in deep water to one trans-Atlantic profile. Until more measurements are made only cursory interpretation of this profile can be made. There is great similarity of the anomaly curve from 170 nautical miles west of Dakar to Barbados. Anomalies of 50 to over 200 gammas, 5-40 nautical miles wide are encountered from the Cape Verde Island region to Barbados. West of Dakar for 170 miles the magnetic field is smooth with anomalies of less than 25 gammas. The topographic contrast between the deep ocean basins and the Mid-Atlantic Ridge is not reflected in the anomaly curve. Large anomalies observed over the submerged parts of the Cape Verde Islands show the effect of known volcanic islands. No anomaly is observed near Barbados or over the continental margin of Africa.

INTRODUCTION

THE evolution of the airborne magnetometer from VACQUIER's flux-gate magnetometer (see DOBRIN 1950) makes possible magnetic surveys of ocean areas without the specially constructed non-magnetic ships formerly required. Although magnetic surveys over marine areas adequate for many purposes (see ALLDREDGE and KELLER 1949, AFFLECK 1948 and BALSLEY 1952) can be made very rapidly with airborne instruments, there are important problems which require a correlation between magnetic anomaly and submarine topography. For any investigation of the magnetic anomaly associated with a given topographic feature on the ocean floor, or with anomalies revealed by other geophysical surveys, it is necessary to make the magnetic measurements continuously and from a vessel capable of making simultaneous depth recordings with good positional control. Through the co-operation of the U.S. Geological Survey (Geophysics Branch) we borrowed in 1948 an airborne magnetometer (Type AN/ASQ 3A, modified for geophysical use) and converted it for towing behind a ship, with the intent to include routine measurements of the magnetic field in future marine explorations.

INSTRUMENTATION

The adaptation for ship operation was simple in principle, requiring only a suitable streamlined, non-magnetic, waterproof case and suitable towing cable. The first

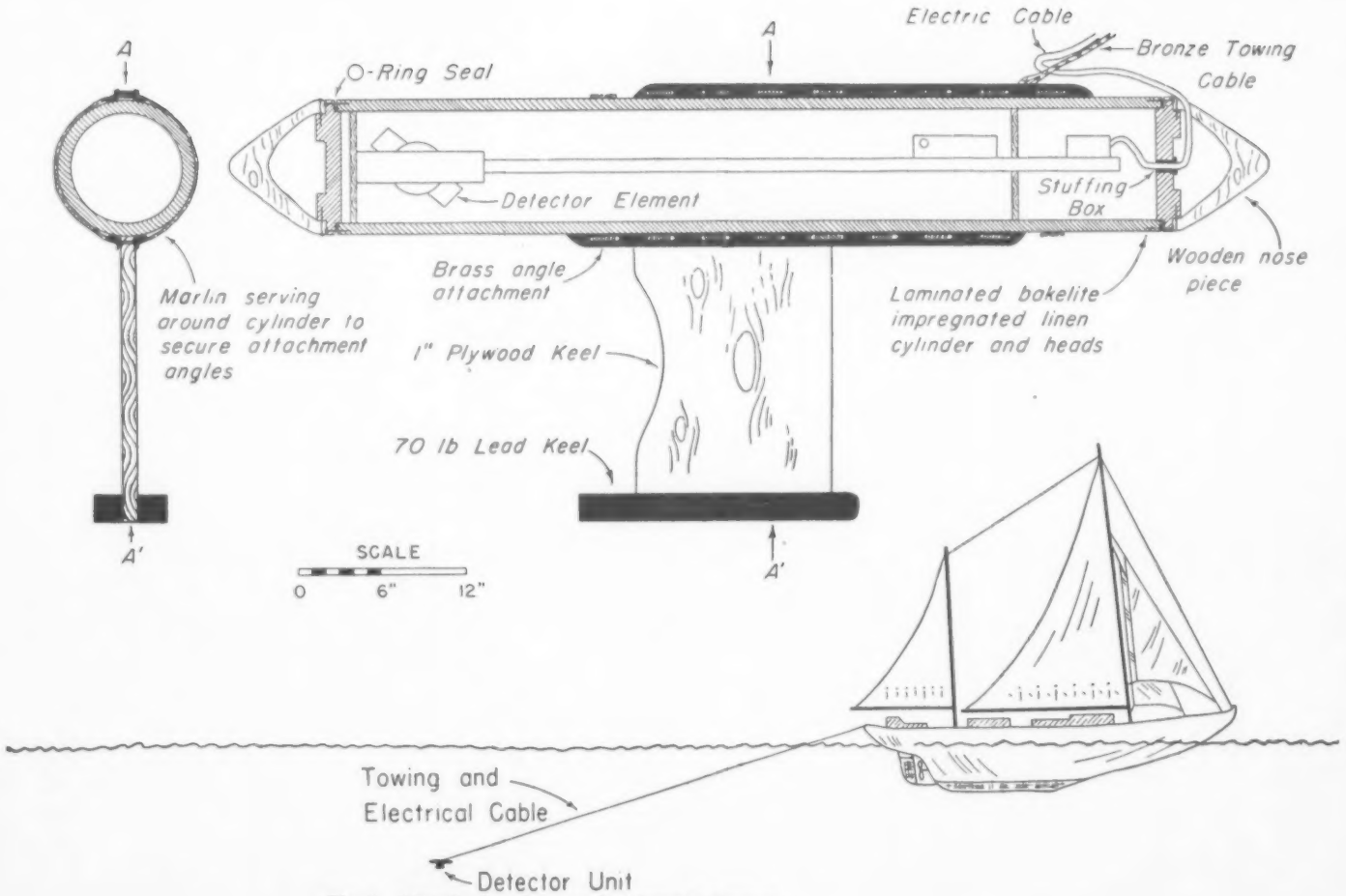

Fig. 1. Detail of towing case for detector element.

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case (Fig. 1) was made of a laminated bakelite tube 8¼ inches I.D., ¾ inch wall, 60 inches long. The ends were closed with plates of the same material sealed with 0-ring gaskets. Wooden fairings and lead keel were added which caused the cylinder to tow nicely at speeds of 9 to 10 knots.

Except for repeated failures of the electrical cable which frequently terminated the magnetic measurements early in a cruise no technical difficulties have been encountered. In the first few years a $\frac{5}{16}$ inch bronze towing cable was used, with a separate 7 conductor table taped to it at intervals (Fig. 1). Broken conductors and leaky insulation led to replacement of this combination by a heavily insulated cable with a central strain member in 1952, when funds for specific support of this research first became available.

Ship-borne operation requires a much greater stability of calibration than had been required of the instrument in aerial mapping since the time involved in a given profile is so much greater. The drifts which are fairly serious in the 1948 data reported here have been subsequently reduced in magnitude until they are no longer serious.

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OBSERVATIONS

Successful observations have been made on seven voyages as follows:

Table I

1.	1948, Oct.-Dec.	R/V *Atlantis* Cruise 153	4,000 miles
2.	1949, July	R/V *Atlantis* Cruise 157	300 miles
3.	1951, July-Sept.	U.S.S. *Stirni*	700 miles
4.	1952, June	*Hazel* III, Cruise 14	500 miles
5.	1952, July	R/V *Atlantis* Cruise 180	500 miles
6.	1952-3, Oct.-Feb.	R/V *Spencer Baird*	7,700 miles
7.	1953, April-June	R/V *Vema* Cruise 1	4,000 miles

The principal results from the first of these cruises is a trans-Atlantic magnetic intensity profile, accompanied by a continuous depth profile from Dakar, French West Africa to Barbados, British West Indies, which will be discussed in the following section. Cruises 2 and 5 are profiles across the continental margin off New England and form part of a study which will be completed by additional data in the near future. Cruises 3 and 4 represent inshore surveys in the New England area (Miller 1952) and are being reported separately. Cruise 6 was the " Capricorn " cruise of the Scripps Institution of Oceanography on which the towed magnetometer measurements were a joint undertaking between that laboratory and the Lamont Geological Observatory. Cruise 7 covers areas from New York to the Caribbean and Gulf of Mexico.

1948 TRANS-ATLANTIC PROFILE

The ship-borne magnetometer was first used on the third Mid-Atlantic Ridge Expedition October-December 1948. Although repeated failures of the electrical cable put the magnetometer out of service for about half the cruise, successful records were obtained on October 18-19, October 23-25 (Figs. 5a, 5b), November 2-3, 7-10

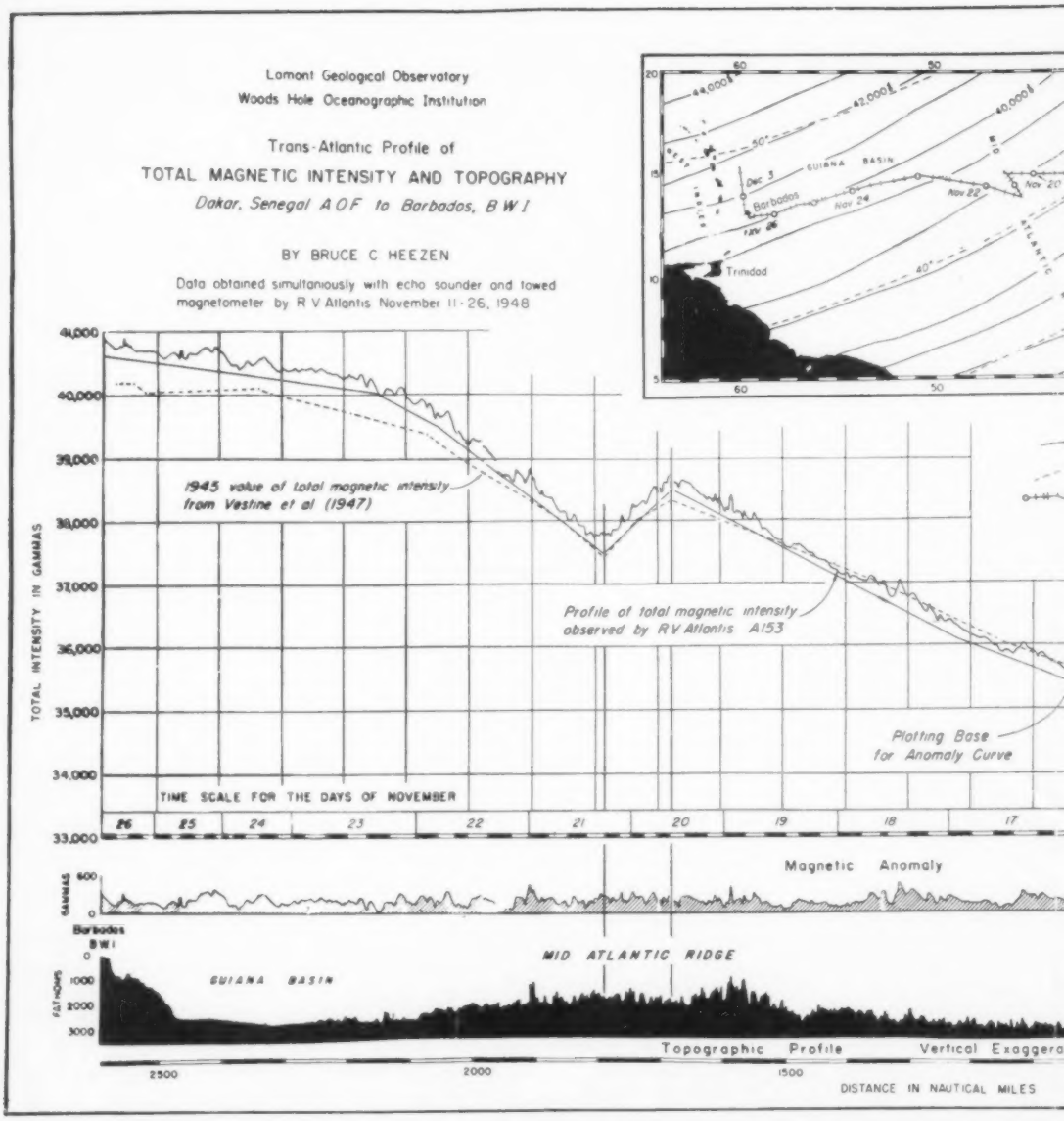
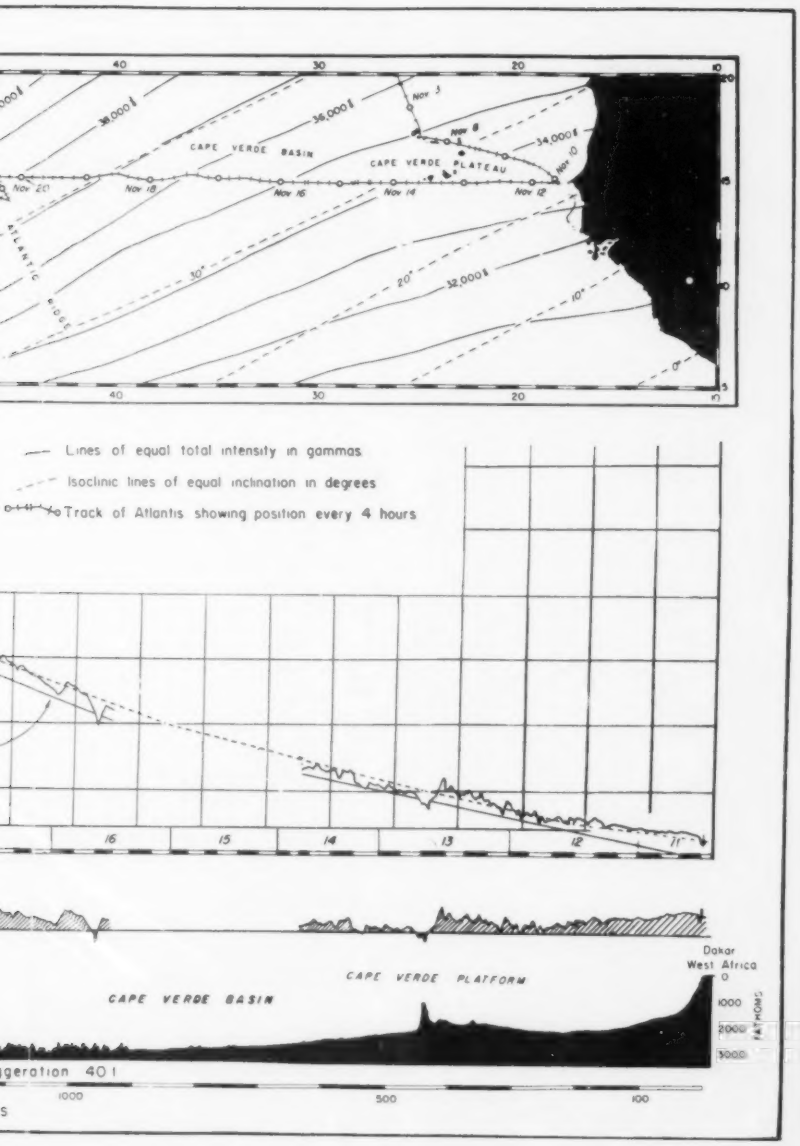

Lamont Geological Observatory
Woods Hole Oceanographic Institution
Trans-Atlantic Profile of
TOTAL MAGNETIC INTENSITY AND TOPOGRAPHY
Dakar, Senegal A.O.F. to Barbados, B.W.I.
BY BRUCE C. HEEZEN
Data obtained simultaniously with echo sounder and towed magnetometer by R.V. Atlantis November 11-26, 1948
Barbados
Trinidad
GUIANA BASIN
MID ATLANTIC RIDGE
ATLANTIC
1945 value of total magnetic intensity from Vestine et al (1947)
Profile of total magnetic intensity observed by R.V. Atlantis A153
Plotting Base for Anomaly Curve
TOTAL INTENSITY IN GAMMAS
TIME SCALE FOR THE DAYS OF NOVEMBER
Magnetic Anomaly
GAMMAS
FATHOMS
Topographic Profile
DISTANCE IN NAUTICAL MILES

Fig. 2. Trans-Atlantic profile of total magnetic intensity and topo



topography, Dakar to Barbados.

(Fig. 4), November 11-14, 16-26 (Fig. 2), and December 2-3 (Fig. 5c). The failure on 3 December was so complete that it was impossible to obtain reliable records for the remainder of the cruise. Each time the cable failed it was necessary to remove some cable and thus bring the detector closer to the ship. From 18-25 October the magnetometer was towed about 300 feet astern, from 2-14 November about 220 feet astern and from 16 November—3 December about 150 feet astern. As the detector was brought in from 300 to 150 feet the background noise increased from less than one gamma to 2-5 gammas. This background, although undesirable, does not seriously affect the value of the data.

In order to determine the effect of magnetic storms on the data obtained, the tabulated mean hourly values for horizontal and vertical intensity at San Juan, P.R. were consulted (U.S.C. & G.S. 1948). For the profile extending from 2 November to 3 December as indicated in Figs. 2, 4 and 5c, a total of nine days had sufficient disturbance at San Juan to be called " moderately disturbed." The rest were classified as quiet. The maximum range in horizontal and vertical intensity is given for these moderately disturbed days in Table 2. The two extreme days, 2 November and 20 November, had respective ranges of: 93 gammas horizontal component, 27 gammas vertical component; and 123 gammas horizontal, 31 gammas vertical. The average for the other days is 51 gammas horizontal, 20 gammas vertical. On the scale for variations in magnetic intensity used in Figs. 2, 3 and 4 these disturbances are rather slight. In any detailed mathematical analysis of this data, magnetic disturbances would deserve further consideration. However, for the purposes of this paper the data may be discussed as it appears.

For the days 18, 19, 20, 23 and 24 October (Figs. 5a and 5b) San Juan recorded moderate disturbance. The only extreme range occurred on 18 October with 138 gammas horizontal and 27 gammas vertical intensity. The average for the other days is 64 gammas horizontal, and 18 gammas vertical (see Table 2).

Table 2

Range in magnetic intensity at San Juan, P.R. (18°22. 9′N 66°07. 1′W) *on "moderately disturbed days" for which profiles are presented.*

Day	*Horizontal*	*Vertical*	*Day*	*Horizontal*	*Vertical*
Oct.			Nov.		
18	138	27	18	41	22
19	86	11	19	31	28
20	39	28	20	123	31
23	69	18	21	57	18
24	60	16	22	58	17
Nov.			24	55	28
2	93	27	25	42	6
17	73	19			

As the magnetometer is designed to measure variations in the total magnetic field an absolute scale for it was obtained by having the data best fit the absolute value of the main field as given by VESTINE *et al.* (1947). No correction was made for diurnal variation. The observed total intensity, VESTINE *et al.* (1947) 1945 main field values,

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and a straight line plotting base are shown on the upper portions of Figs. 2, 4. The anomaly curve is the difference between the observed value and the arbitrary straight line plotting base. The depth profile was plotted at 40: 1 exaggeration from the echogram obtained by a NMC-1 echo sounder using the standard sounding velocity of 800 fathoms per second. The time scales are given in local zone time. Changes from zone + 1 through + 4 were made at 0100 on 14, 18 and 23 November.

DISCUSSION OF DATA

Until more is known of the topography and more magnetometer surveys are run only a few general conclusions can be drawn. Perhaps the most striking characteristic of the data is the general similarity of the magnetic field from 170 miles west of Dakar to Barbados. West from Dakar for about 170 miles on both tracks (Figs. 2 and 4) the field is smooth with anomalies of less than 25 gammas. Anomalies of 50 to over 200 gammas, 5-20 miles across, are encountered on the Cape Verde Platform south of the Cape Verde Islands. Across the Cape Verde Basin, Mid-Atlantic Ridge, Guiana Basin on to Barbados the anomaly curve is quite similar with anomalies up to 150 gammas in magnitude and up to 40 miles across. Although no simple direct correlation between submarine topography and magnetic intensity would be expected some correlation of periodicity and magnitude of anomaly should be expected if the anomaly were explained by the relief. No direct correlation between submarine topography and magnetic intensity is seen. Because of the moderate angle of dip as shown in the insert in Fig. 1, this might not seem surprising even if such a correlation did exist. However the profiles on 2-3 November and 20-21 November are almost parallel to the horizontal component of the field and direct correlation is again lacking even when the magnetic anomaly is translated a short distance with respect to the bathymetric data.

There is no definite magnetic anomaly which can be identified as associated with the structure east of Barbados. The north-south profile lying just west of Barbados reveals an extremely uniform magnetic field for almost 200 nautical miles. Barbados, a limestone island, probably underlain by thousands of feet of lime sediments (WORZEL and EWING 1948; EWING and WORZEL 1953) would not be expected to exhibit any significant anomalies. This is noteworthy in the light of the submarine gravity anomaly there. While the anomaly curve is generally the same across the Atlantic, there is a slight but noticeable difference over the centre of the Mid-Atlantic Ridge and also over the eastern part of the Cape Verde Island Platform (1600, 12 November to 1600, 13 November). In those regions anomalies of small horizontal extent (less than 10 miles across) and amplitudes around 100 gammas are frequently observed. This effect, presumably due to the decrease in distance to the polarized crystalline rock, is not as extreme as the stronger topographic contrast between the smooth floor of the ocean basin and the Mid-Atlantic Ridge. No definite anomaly is associated with the clearly defined continental margin at Dakar.

The conspicuously large anomalies near St. Vicente Island and the large anomalies over the shallow water just south of Sal Island (Fig. 4) in the Cape Verde Archipelago, with characteristic high curvature of the field, show the effect of known volcanic islands. Note that north of St. Vicente only positive anomalies are observed while in crossing to the south of Sal Island both a positive and negative anomaly is found.

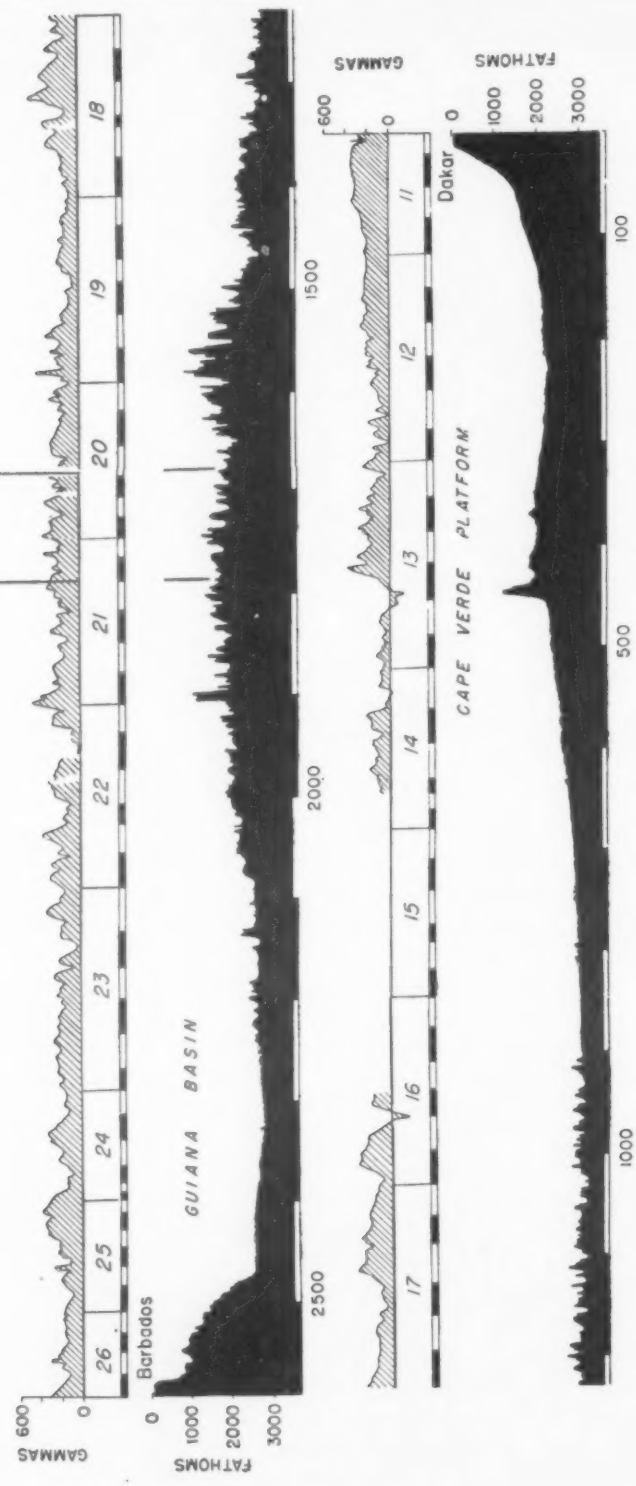

Fig. 3. Detail of anomaly curve and topography, Trans-Atlantic profile.

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There are currently available in the literature aeromagnetic profiles for three tracks all quite remote from the ones under discussion. One from Adak, Alaska across the Pacific to Kwajalein (ALLDREDGE and KELLER 1949) reveals considerable anomalies over most of the track. However, there are extended sections of over 100 miles where the field is quite uniform. Exceptionally large changes are found over the islands crossed. The amplitudes and half widths, over Midway Island especially, appear quite similar to the prominent features seen over the shoal regions of the Cape Verde Arhipelago. AFFLECK (1948) has presented an aeromagnetic profile from Venezuela to Texas. Again most of the track is anomalous, but with relatively smooth field found in sections of the Caribbean and much of the Gulf of Mexico. JENSEN (1949) published, at a relatively large scale, an aeromagnetic profile along the 40th Parallel from Eastern Colorado to Western Indiana. Anomalies in excess of 100 gammas which are less than 10 miles across cover most of the profile. In addition there are changes of hundreds of gammas over distances of 40 miles. The above profiles are mentioned because they represent the only readily available published data which are comparable to those presented here.

The magnetic observations reported in this paper, being taken at sea level, were generally made more than $1\frac{1}{2}$ miles above the ocean bottom. At such a distance anomalies of several hundreds of gammas amplitude, exceeding 20 miles in width, are probably due to changes in the polarization of the rock below and not directly to topography or structure in common granitic or basaltic rock. To appreciate the magnitude involved simple calculation can readily be made using formulae developed by PRESS and EWING (1952). Consider the anomaly of a vertical fault with a displacement one quarter of the depth to the upper surface when the fault is oriented East-West (magnetic). In a field of 30,000 gammas horizontal intensity, 25,000 gammas vertical intensity, and the susceptibility contrast 0·01 cgs, the anomaly has an amplitude of 174 gammas approximately over the fault, and the N-S horizontal distance between points where the anomaly is 77 gammas is 2·1 times the depth to the top. The anomaly would be positive if up on the north side and negative if up on the south. Thus if the upper surface was 12,000 feet below the sea with a throw of 3,000 feet on the fault face, a minimum horizontal distance of 4·2 miles would separate points where the anomaly was one-half its extreme value. Any decrease in susceptibility contrast would proportionally decrease the anomaly. There would be a marked decrease as the orientation of the fault was deflected from an E-W (magnetic) direction. The conditions postulated are extreme and many factors would tend to greatly reduce the anomaly.

Susceptibility contrasts accomplished by polarization changes taking place over a thick column of rock can theoretically produce large anomalies (VACQUIER *et al.* 1951). Thus while structure and topography undoubtedly cause many of the smaller anomalies observed, the large changes are more readily visualized as the result of changes in the magnetic properties of the rock column. This suggests that along the profiles presented there is a heterogeneity of material directly beneath the ocean floor as far as magnetic properties are concerned.

The fact that the same large scale anomalies are only a few miles across necessitates the belief that the upper surface of the body causing them must lie relatively close to the bottom of the ocean.

The fact that the magnetometer makes measurements continuously along the

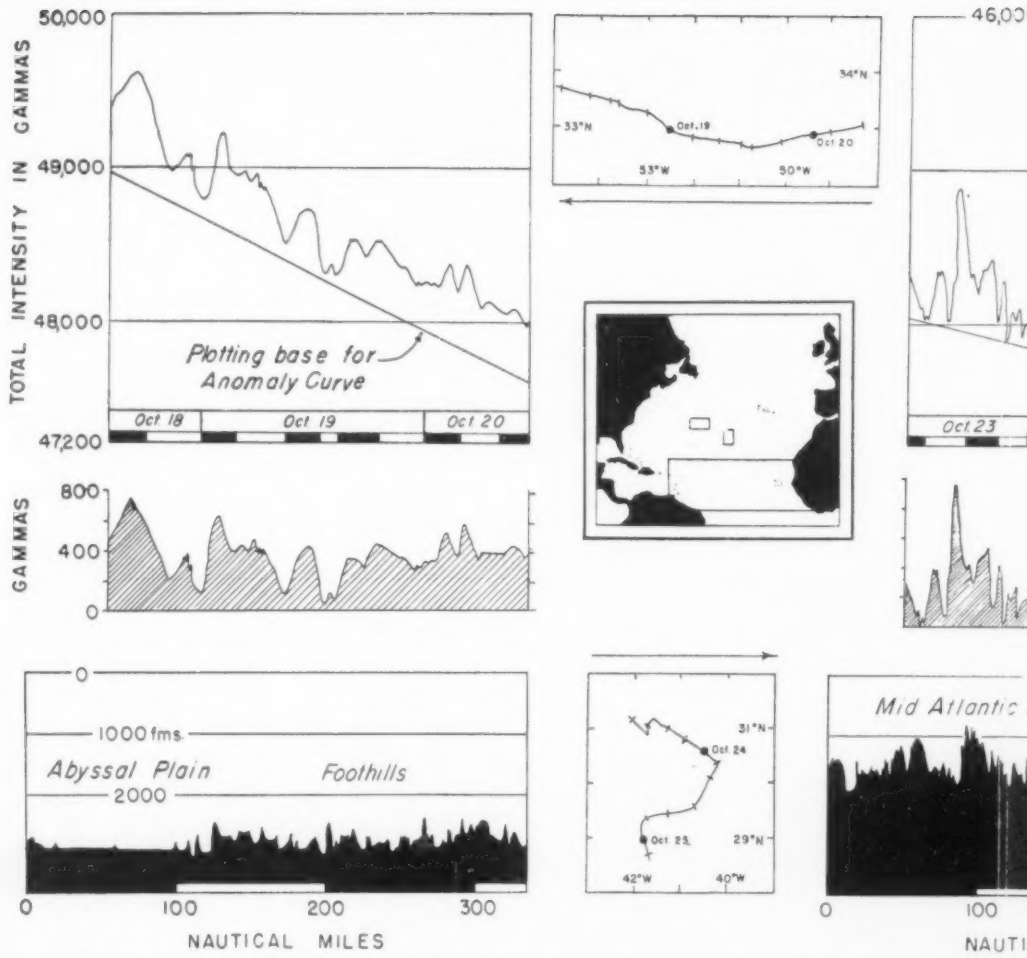
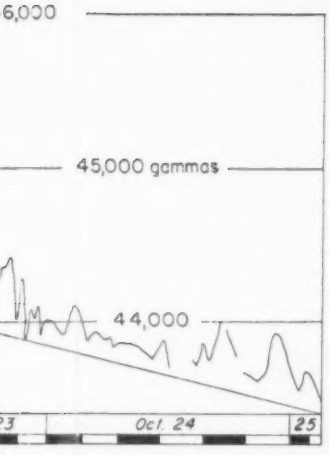
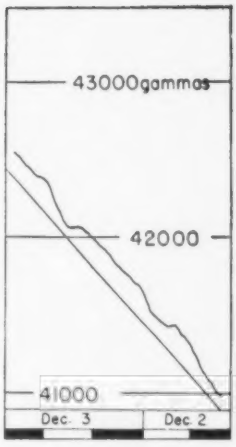
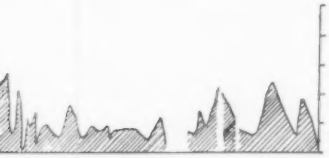
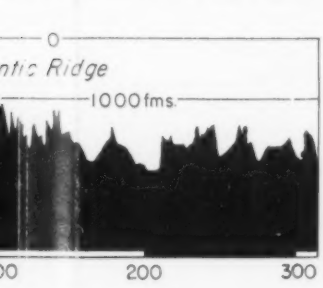


Fig. 5. Three short profiles of total magnetic intensity and topography. (a) Abyssal plain and western foo
(c) Profile north of Barbados.

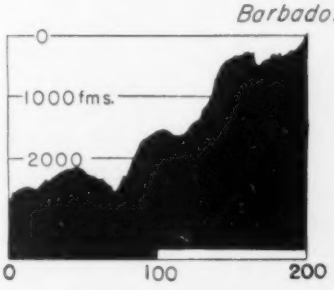








rn foothills of Mid-Atlantic Ridge



(b) Highlands of Mid-Atlantic Ridge

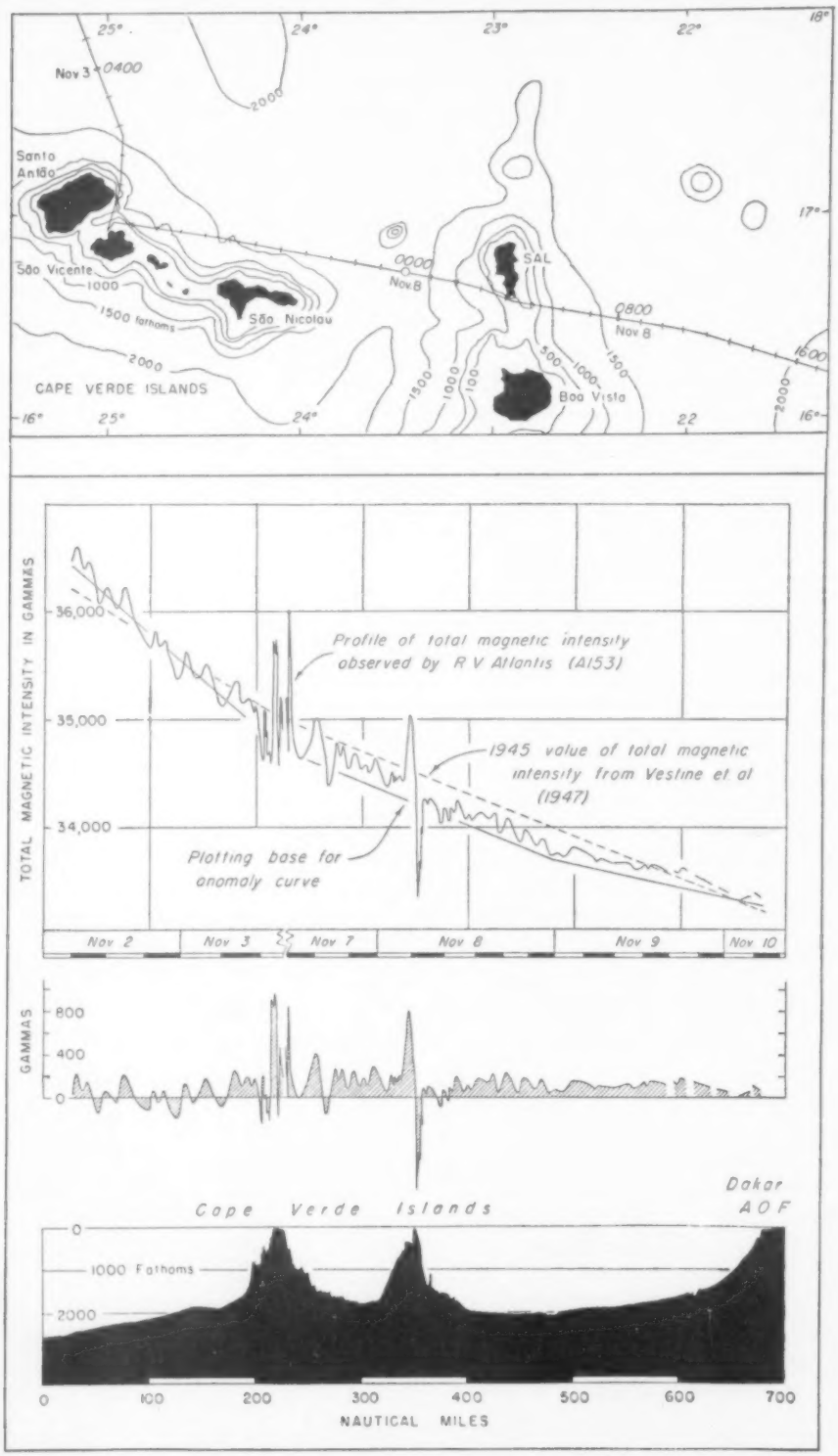


Fig. 4. Profile of total magnetic intensity and topography Cape Verde Archipelago to Dakar.

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vessel's track makes it ideally suited as a method to study and define areas of a certain type of physical heterogeneity in the oceans. The potentialities of this method of geophysical study should be recognized. The fact that it is a continuous measurement and can be made a routine operation makes it an important technique for defining natural regions of the relatively inaccessible oceanic areas. Ship-borne use provides good positional and depth information and allows the accumulation of much mutually supporting geophysical and geological information as work progresses.

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Rôle des Flagellés calcaires dans la fertilité et la sédimentation en mer profonde

F. BERNARD

(*Received May 1953*)

Summary—Some quantitative data are given here on calcareous flagellates, showing their importance in deep seas, as shown by recent work in the Atlantic Ocean and in the Western Mediterranean.

1. The systematics are as yet very provisional. One may distinguish, however, five " species " common to depths below 1,000 metres. *Coccolithus fragilis* Lohm., is prevalent in warm and temperate seas, between depths of 0 to 3,000 metres. *C. wallichii* Lohm., *Corisphaera fagei* Bernard and *Syracosphaera profunda* Bernard are abundant in warm seas, chiefly below 200 metres. The aberrant *Thoracosphaera heimi* (Lohm.) is oceanic and inhabits colder layers ($< +3°C$, the first three forms $< +8°C$).

2. The number of cells per litre is estimated by means of a reversed microscope, after sedimentation of stained water in small glasses. Between the depths of 1,000 and 3,000 m, *Coccolithus fragilis* generally has 7,000 to 240,000 cells, the other species giving counts of only 4,000 to 100,000 cells. The isolated spores of *C. fragilis* are even more common, which explains the great resistance of these flagellates to unfavourable waters.

3. The rate of cell-division seems to be rather low. The number of Coccolithus near the surface grows at the rate of about 1/6 per day, and, after 8 days of such multiplication, a rest is almost always observed in the Mediterranean. In the coastal waters of Algeria, the annual production of *C. fragilis* per cubic metre is calculated at 36 g, containing about 9 g of calcareous material.

4. Since the coccoliths are very thin, at most 5 per cent by weight survive to be deposited in deep-sea muds. However, the calcareous plates, more or less dissociated in granules, make up from 15 to 30 per cent of the dry weight of sediments, at 2,000 m depth off Algiers. The same deposits are rich in thick plates of extinct coccolithophorids, derived from Tertiary rocks of the African coast.

5. The total volume of calcareous flagellates per litre generally amounts to more than 50 per cent, and often 95 per cent, of the phytoplancton in the bathypelagic zone, other algae present being chiefly Myxophyceae (*Nostoc*, *Microcystis*, etc. . . . .). Thus, the coccolithophorids are the chief subscribers to deep-sea fertility and sedimentation, down to a depth of 4,000 m and probably even deeper.

Résumé—Basé sur les Expéditions modernes dans l'Atlantique et sur nos propres observations en Méditerranée occidentale, ce travail a pour but de préciser quantitativement l'importance des Flagellés calcaires dans les eaux et les sédiments profonds de ces régions.

1°. La classification de ces Protistes est encore à un stade très provisoire. En adoptant, faute de mieux, la systématique actuelle, on peut citer 5 " espèces " communes au dessous de 1.000 mètres. Ce sont: *Coccolithus fragilis* Lohm. (toutes mers chaudes et tempérées, dominant de 0 à 3.000 mètres), *C. wallichii* Lohm., *Corisphaera fagei* Bernard, *Syracosphaera profunda* Bernard (mers chaudes, surtout au dessous de 200 m.), enfin le singulier *Thoracosphaera heimi* (Lohm.), océanique, habitant des couches plus froides (3 à 8°, au lieu de 8 à 26° pour les autres formes).

2°. Leur nombre de cellules par litre, obtenu par sédimentation de l'eau, révèle une fertilité relativement considérable. Entre 1.000 et 3.000 mètres, ce nombre varie de 7.000 à 240.000 chez *Coccolithus fragilis*, de 4.000 à 100.000 pour l'ensemble des autres espèces. Les spores isolées de *C. fragilis* se comptent souvent par millions au litre, et cette facile sporulation explique la résistance de cette forme à des milieux défavorables, non tolérés par les autres Coccolithophorides.

3°. La vitesse du multiplication semble assez faible: en moyenne, le nombre de *Coccolithus* en surface n'augmente que d'un sixième par jour, et cet accroissement ne se maintient guère plus de

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8 jours sans interruption: il y a ensuite des phases d'arrêt dues aux changements du milieu marin. Dans les eaux côtières d'Algérie, la production annuelle de *C. fragillis* par mètre cube d'eau est évaluée à 36 grammes, dont environ 9 grammes de calcaire.

4°. Les coccolithes étant très minces, au plus 5% de cette masse annuelle arrive à se sédimenter dans les vases profondes méditerranéennes. Toutefois, ces plaques de calcite, plus ou moins dissociées en granules, doivent constituer encore près de 75% du poids sec des sédiments, vers 2.000 mètres, au large d'Alger. Il s'y ajoute des plaques épaisses, entières, provenant de grands Flagellés fossiles du Tertiaire littoral.

5°. Si la majorité des espèces paraît avide d'oxygène et d'eau très pure, les formes bathypélagiques supportent de basses teneurs en 0_2. Leur volume total par litre représente de 30 à 95% du phytoplancton profond, les autres Algues hétérotrophes locales étant surtout des Cyanophycées des genres *Nostoc* et *Microcystis*. Il y a donc lieu d'accorder un intérêt majeur aux Coccolithophorides pour l'étude de la fertilité et des sédiments, jusqu'a 4.000 mètres de profondeur et sans doute davantage.

L'IMPORTANCE sédimentaire des Coccolithophorides est signalée depuis longtemps, et confirmée par 15 ans de recherches récentes sur les microfossiles (voir notamment DEFLANDRE, 1936 et 1952; KAMPTNER, 1948 etc.). Mais la plupart des auteurs considèrent surtout ces Flagellés comme des êtres de mer chaude et peu profonde, interprétant même comme néritiques les dépôts où se trouvent leurs squelettes. Ils négligent ainsi bien des résultats océanographiques, obtenus dans des régions diverses, et prouvant l'abondance du groupe à des niveaux marins très variés, parfois dans des eaux relativement froides. Si, dans les vases profondes, les plaques minuscules (coccolithes) sont souvent altérées et indéterminables, cela n'enlève rien au fait que ces corpuscules forment une grande part du calcaire présent dans chaque litre d'eau de mer et dans les sédiments des régions tempérées et tropicales, souvent trés au dessous de 2.000 m.

Je voudrais, par la présente note, attirer l'attention des océanographes sur ce rôle quantitatif des Flagellés calcaires, les conditions de production et de dépôt de leur squelette, et sur les multiples problèmes biologiques posés par leur mode de vie.

I° PRINCIPALES FORMES

La définition de l'espèce est encore très incertaine ici pour trois raisons. D'abord, parce que ces Unicellulaires semblent dépourvus de sexualité et montrent une variabilité somatique très étendue. Ensuite, par ce que la systématique, à défaut de mieux, est encore basée entièrement sur l'aspect des plaques calcaires. Enfin, la structure réelle de ces plaques est très compliquée, comme le prouvent les études récentes de BRAARUD (1952) au microscope électronique: leur forme, vue au microscope ordinaire, renseigne très mal, et nos dénominations seront provisoires.

L'espèce dominante est *Coccolithus fragilis* Lohmann (Fig. 1) pouvant pulluler de 11° à 30° centigrades et de 33,5 à 39 ‰ de salinité. Sa résistance à des conditions extrêmes, à une faible oxygénation notamment, est explicable par la très facile formation de spores internes ovoïdes, longues de 4 à 10 μ, colorées en noir ou en rouge-orangé par des pigments très stables. La nature mélanique de ces pigments (établie par J. LECAL-SCHLAUDER, 1948) permet leur conservation dans les sédiments anciens et récents. Même une marne jurassique, préparée par G. DEFLANDRE à Paris, contenait des stades (spores et palmelles) de ce *Coccolithus*, encore teintés en jaune-foncé ou en brun.

En milieu favorable, les *Coccolithus* de taille moyenne (12 à 30 μ) perdent leurs fouets, augmentent de volume par gélification de leur coque, et se divisent, constituant ainsi des amas volumineux de 300 à 1.000 cellules, visibles à l'oeil nu comme de petits grains rouge-orangé dans la mer. C'est le stade palmelloïde, bien plus dense

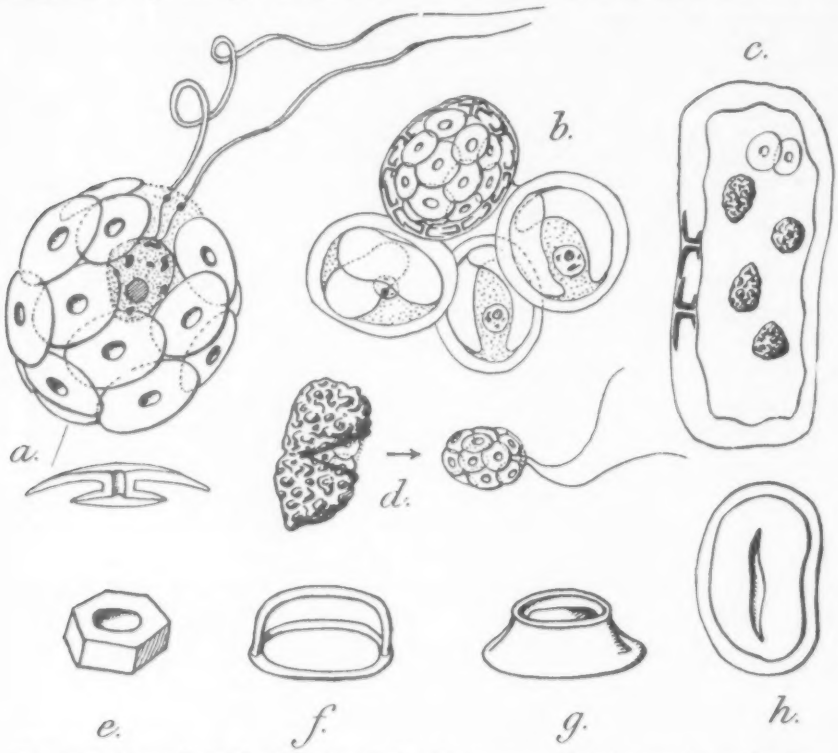

Fig. 1. Schémas des 5 Flagellés calcaires les plus communs dans les grandes profondeurs marines. (*a*) à (*d*) *Coccolithus fragilis* Lohm. et résumé de son cycle; (*a*) cellule complète, de 15 à 20 à, couverte de grandes plaques en forme de bouton-pression (trémalithes) dont l'une est figurée au bas en coupe sagittale, avec son pore; le noyau, les 2 blépharoplastes et les 2 flagelles (légèrement hétérodynames) sont représentés d'après J. LECAL (1951); (*b*) stade palmella, phase de division sans coque gélatineuse épaissie et sans flagelles: ce stade 4 montre une cellule (en haut) avec son squelette figuré, dans les 3 autres éléments les plaques ne sont pas dessinées et l'on voit 2 plastes, rouge orangé, en croissants, dans chaque cellule; (*c*) cellule palmelloïde grosse et cylindrique, souvent observée en profondeur à Monaco; 4 plaques seulement sont figurées, deux à gauche en coupe et deux, en haut, de face. 4 spores internes brunes existent dans ce *Coccolithus*, dont le reste du protoplasme a disparu; (*d*) éclosion d'une spore (à carapace granuleuse, non calcaire) donnant naissance à un jeune Flagellé; (*e*) plaque de *Thoracosphaera heimi* (Lohm), type bathypélagique aberrant, à plaques en pavage polygonal, qui n'est peut être pas un vrai Coccolithophoride; (*f*) plaque (zygolithe) de *Corisphaera fagei* Bernard, en forme d'étrier évidé; (*g*) plaque (discolithe) de *Syracosphaera profunda* Bernard, en forme d'encrier à fond convexe; (*h*) trémalithe de *Coccolithus wallichii* Lohm., vu en dessous, par la plus petite plaque interne.

que l'eau, car il conserve des " trémalithes " calcaires dans les coques gélifiées: ces amas tombent en quelques secondes au fond d'un bocal haut de 40 centimètres.

S'il y a pénurie de nourriture (de phosphates et nitrates dans la zone éclairée, probablement de substances organiques dans la zone profonde), ou variation trop brusque du milieu, *C. fragilis* change de teinte, devenant noirâtre dans tout le proto-

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plasme. Ce rembrunissement est préliminaire à la formation de spores internes (4 à 64 par cellule selon les cas, 8 ou 16 étant les nombres les plus fréquents). Même les palmellas peuvent engendrer des spores. Plus rarement, près des côtes, mais très souvent au grand large (à plus de 60 milles d'un plateau continental), il y a enkystement et non sporulation, la cellule étant alors recouverte d'une carapace sphérique de prismes calcaires serrés, en plus de son squelette normal. Ce cycle, entrevu seulement par LOHMANN en 1921, a été précisé par F. BERNARD en 1939.

Grâce à ces phases de résistance (spores et kystes), *Coccolithus fragilis* ne manque jamais dans les mers chaudes les mieux connues (Atlantique central, Méditerranée): il fournit toujours, au minimum, quelques milliers de spores et de cellules par litre d'eau, de 0 à 2.000 mètres et probablement plus bas. L'optimum de profondeur semble situé vers 50 mètres dans la couche ensoleillée, vers 400 mètres dans les couches obscures (où les Flagellés sont vraisemblablement hétérotrophes). A lui seul, *C. fragilis* fait en moyenne 90% du volume des Coccolithophorides par litre, et 20 à 80% du nannoplancton total. Au contraire, les 140 autres " espèces " décrites sont moins pérennes et plus limitées verticalement: leur sporulation peu fréquente, les kystes rares ou nuls, doivent laisser les cellules plus exposées aux changements marins. Leur distribution témoigne d'un besoin d'oxygène très grand: ce sont des organismes " oligotrophes," d'eaux claires (voir à ce sujet F. BERNARD, 1942).

En grand majorité, ces formes habitent la couche éclairée moyenne (30 à 200 mètres en Méditerranée, 10 à 100 mètres dans les océans tropicaux), mais quelques unes, encore assez mal connues morphologiquement, augmentent d'abondance vers les couches profondes (300 à 4.000 mètres et sans doute plus bas). Telles sont, pour se borner aux plus communes: *Coccolithus wallichii* Lohm., *Syracosphaera profunda* Bernard, *Corisphaera fagei* Bernard, et surtout *Thoracosphaera heimii* (Lohm.), dont les plaques sont fréquentes dont les vases abyssales (Fig. 3). Elle supporte des eaux entre + 3° et 8° dans l'Océan, les autres espéces vivent au dessus de + 8°.

En Méditerranée, ces Flagellés sont toujours accompagnés, plus ou moins densément, par *Coccolithus fragilis*. Dans la seule mer ouverte étudiée à cet égard (Atlantique central et austral, par LOHMANN 1921 et HENTSCHEL 1936), *C. fragilis* parait moins fréquent au-dessous de 500 mètres. Mais LOHMANN et HENTSCHEL n'en avaient pas identifié les spores et kystes, que j'ai trouvés très nombreux par litre dans les parages des Açores et du Sénégal (croisière du *Président Théodore Tissier*, 1936).

Donc, 5 formes au moins, dont deux particulièrement répandues (*Coccolithus fragilis* et *Thoracosphaera heimii*) peuplent les eaux profondes. Quelques exemples vont préciser leur densité habituelle:

2° DENSITÉ DES CELLULES À DIVERS NIVEAUX. DÉDUCTIONS BIOLOGIQUES

Très petits et déformables, les Coccolithophorides échappent aux filets les plus fins. Par centrifugation (méthode d'HENTSCHEL, justement critiquée par STEEMANN-NIELSEN), leurs coques gélatineuses s'accolent aux parois des tubes, et plus des 2/3 des cellules sont perdues. Le seul procédé de numération actuellement valable est la sédimentation lente de l'eau de mer, fixée à bord au moyen de formol neutre ou de sublimé. De dépôt se fait sur le fond mince de petits vases de 10 à 40 cc, où l'on peut compter les éléments au microscope inversé. 6 à 12 heures suffisent pour une sédimentation complète.

Les nombres trouvés sont de l'ordre de 5.000 à 3 millions de cellules par litre, soit généralement plusieurs centaines (spores comprises) par centimètre cube.

Les résultats cités au tableau 1 sont tirés de mes propres comptages pour la Méditerranée au large de Monaco (M.) et de l'Algérie (Al.). Pour l'Océan Atlantique (O.), mes données moyennes à 50 et 350 mètres proviennent de la croisière du *Président Théodore Tissier* (1936) et se montrent 3 à 10 fois plus élevées que celles d'HENTSCHEL (croisière du "*Meteor*," 1933-36) obtenues par centrifugation. A titre d'estimation provisiore, pour les couches atlantiques au-dessous de 300 mètres, je multiplierai par 5 les résultats de l'auteur allemand. On obtient encore ainsi des densités océaniques nettement inférieures à celles des niveaux correspondants de la Méditerranée côtière, sauf à 500 mètres où les 3 régions connues semblent également fertiles. Mais il faut noter: 1° les températures profondes, plus basses dans l'océan, ce qui désavantage les Flagellés calcaires. 2° l'éloignement des côtes, beaucoup plus grand pour les stations atlantiques, d'où manque de substances nutritives. Cela explique la rareté des stades de division (palmellas) dans les échantillons pélagiques de la *Deutschland*, du *Meteor* et du *Théodore-Tissier*.

Tableau 1

Exemples de densité des Flagellés calcaires (nombre de cellules par centimètre cube) en 3 régions marines. Le niveau de 50 m a été choisi comme type dans la couche éclairée, car il paraît correspondre généralement à un optimum de photosynthèse pour ce groupe.

M = parages de Monaco, à 6-7 milles de la côte (moyenne de 20 stations en toutes saisons 1938);
Al = parages de l'Algérie à 12 milles des côtes d'Oran Ténès et Alger (moyenne de 16 stations de Mais à Juillet 1950 et 1952);
O = Atlantique pélagique tropical à plus de 60 milles du talus continental africain de 9 à 24° de latitude N et de 18 à 30° de longitude W. Moyenne de 20 stations. De 50 à 350 mètres résultats du *Président Théodore Tissier* (F. BERNARD 1939). De 500 à 4.000 mètres données du *Meteor* (HENTSCHELL 1936) multipliées par 5 en raison des erreurs moyennes dues à la centrifugation.

Enfin, la dernière colonne (R.), indique le nombre maximum record noté jusqu'à présent pour toutes les mers (généralement au large de l'Algérie ou du Sénégal), pour donner une idée des capacités limites de multiplication des espèces.

Profondeur (mètres)	*Coccolithus fragilis*												*Thoracosphaera heimii* + *Syracosphaera profunda**			
	Palmellas				*Cellules non en division ou kystes*				*spores isolées*							
	M.	*Al.*	*O.*	*R.*	*M.*	*Al.*	*O.*	*R.*	*M.*	*Al.*	*O.*	*R.*	*M.*	*Al.*	*O.*	*R.*
50	25	155	0,6	1300	40	147	71	3000	300	880	850	2200	10	3,2	1	64
300-400	19	185	2	1900	48	112	92	1500	255	1470	1160	3200	8	1,2	1,8	66
500	10	81	1	850	31	39	40	95	250	860	320	2000	14	1,5	3	73
1.000	8	38	0,2	105	17	62	12	132	530	1200	270	2200	18	2,0	4	87
2.000	–	27	0,4	80	–	54	5	250	–	850	40	1800	–	4	9	80
4.000	–	–	?	–	–	–	2	?	–	–	?	–	–	–	7	40

* Ces 2 espèces, très pigmentées en brun, à plaques épaisses, ont du être souvent confondues entre elles dans les numérations.

La figure 2 résume, sous forme graphique, les comparaisons quantitatives entre les 3 régions.

Il serait prématuré de tirer des conclusions définitives de tels résultats, qui ne portent que sur une soixantaine de stations, à des saisons différentes et dans des

zones marines assez spéciales. Cependant, assez de faits sont communs aux trois régions étudiées pour permettre des remarques sur la distribution verticale des Coccolithophorides:

(*a*) Leur décroissance de densité vers le bas est moins forte et moins régulière

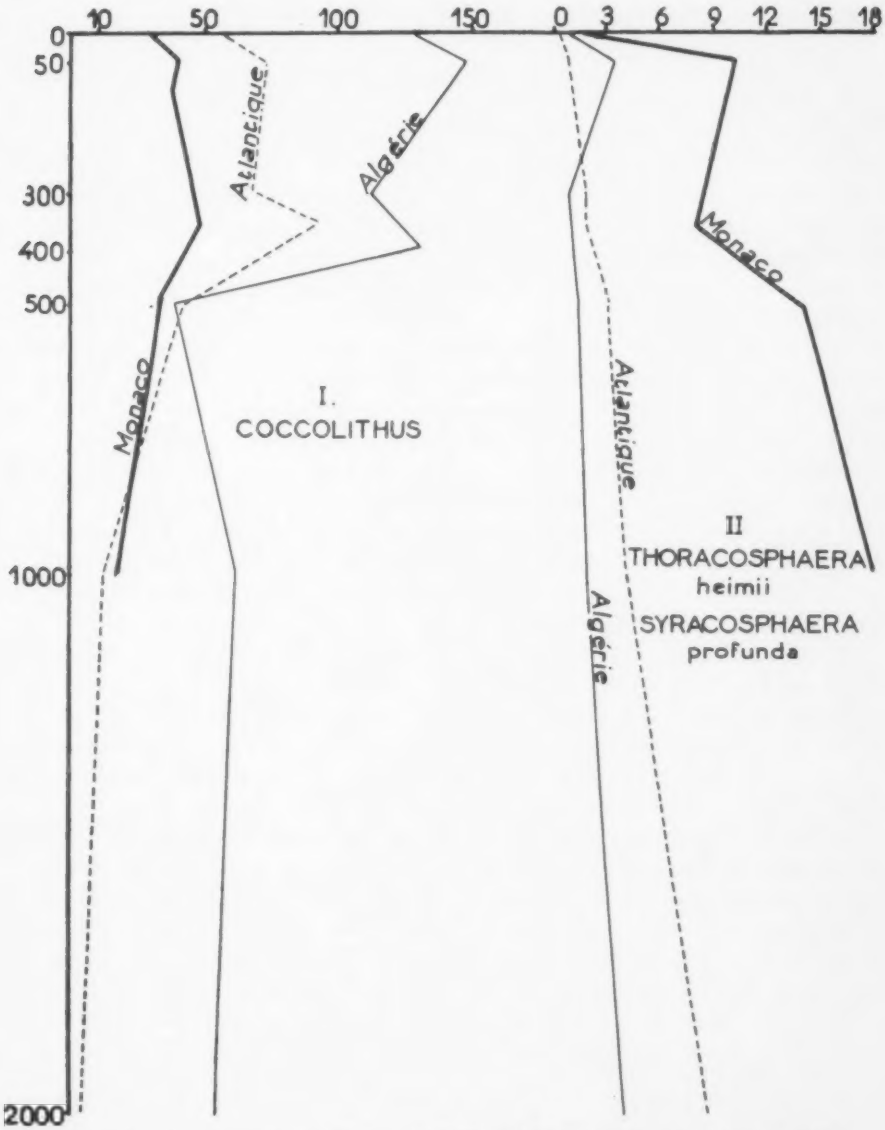

Fig. 2. Répartition quantitative moyenne des Flagellés calcaires dans 3 régions marines (pour la signification des termes: Monaco, Algérie et Atlantique, voir la légende de tableau 1 ci-dessous). En haut, nombres moyens de cellules par cc d'eau de mer; verticalement profondeurs en mètres. (I) Cellules de *Coccolithus fragilis* (spores non comprises). Les maxima vers 50 et 400 mètres paraissent correspondre à des courants locaux riches en substances nutritives. (II) total de *Thoracosphaera* + *Syracosphaera*. On remarquera son accroiseement vers le bas, surtout à Monaco, dont les eaux sont plus pures.

que l'on ne croyait autrefois. Entre 300 et 400 mètres, il y a souvent plus de cellules qu'à 50, et les nombres record y sont plus grands. A 500 mètres, on note près de 60% des valeurs obtenues dans la couche èclairée. A 1.000 et 2.000, les moyennes représentent 20 à 30% de celles de cette même couche. A 4.000 mètres, où les données sont fragmentaires, *Coccolithus fragilis* est encore souvent représenté, et les autres formes sont plus abondantes qu'à 1.000 mètres.

Mais, à partir de 500 mètres, les maxima de ce nannoplancton sont bien plus faibles qu'en surface: le taux de variation annuel ne doit guère y dépasser 4, au lieu de 10 à 50 plus haut.

(*b*) Cette fertilité profonde peut s'expliquer par la nutrition hétérotrophe: comme beaucoup d'autres Flagellés colorés, certains genres calcifiés doivent absorber, en l'absence de lumière, des substances organiques ou peut-être des Bactéries. On doit aussi invoquer les phénomènes de *chute*, certains dans le groupe qui nous occupe. Les divers stades sans flagelles (palmellas, spores, kystes) sont manifestement plus denses que l'eau et tombent passivement vers les grands fonds. Nous étudions actuellement ce processus sur les amas palmelloïdes, visibles à l'oeil nu, de *Coccolithus fragilis*. Cette considération modifie, entre autres, les théories sur le cycle de la matière vivante océanique, puisque des cellules autotrophes de surface, productrices de vitamines, tombent sans cesse, en pluie serrée, vers la zone obscure où elles fournissent des aliments riches aux Bactéries et aux Animaux.

Il est bien difficile de dire si cette chute atteint des niveaux très profonds, car les courants peuvent détourner ou même remonter une partie des cellules, et leur substance doit être à la longue décomposée par les Bactéries. Mais l'état de fraîcheur des spécimens fixés, ramenés depuis 1.000-4.000 m, autorise à dire qu'une bonne partie d'entre eux vivaient et prospéraient sur place, une fraction seulement pouvant provenir des couches supérieures.

Par contre, l'existence d'une forte densité et de maxima surprenants vers 400 mètres, niveau sans lumière où les ressources nutritives sont plus faibles qu'en surface, peut s'expliquer par l'accumulation périodique dans cette couche, d'éléments venus de la zone euphotique, arretés ici par une densité ou une viscosité plus grande de l'eau.

(*c*) Un cas particulier est celui des spores, minimes cellules de 4 à 9 μ, entraînables facilement par les moindres courants.

A l'inverse des autres stades de *Coccolithus*, leur densité moyenne (de l'ordre de 700 par cc.) et maximum (de l'ordre de 2.000) changent peu avec la profondeur. On en trouve aussi beaucoup dans les vases profondes, et les courants ascendants peuvent en disperser de là dans toute la mer. La numération des spores présente donc peu d'intérêt biologique, et on ignore si une spore provenant d'un Flagellé de surface peut éclore à 1.000 mètres, ou réciproquement. C'est peu probable, si l'on en juge par les conditions assez restrictives d'éclosion des spores en surface à Monaco (F. BERNARD, 1948): même l'espèce très robuste *Coccolithus fragilis* possède sans doute des races profondes et des races de la couche éclairée, distinctes physiologiquement. Jusqu'ici, aucune différence morphologique n'a pu être affirmée à cet égard.

(*d*) Au-dessous de 400 mètres, les concurrents habituels des Coccolithophorides (Diatomées, Péridiniens, Chrysomonadines, etc.) deviennent rares ou nuls. Il ne subsiste comme autres éléments visibles du nannoplancton que des Cyanophycées (*Nostoc*, *Microcystis*, *Dactylococcopsis* etc.) plus abondantes dans l'Océan et en Algérie qu'à Monaco.

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3° EVALUATION DE LA PRODUCTION DE CALCAIRE

Il est assez facile d'estimer, d'après la forme des plaques, combien une cellule moyenne de *Coccolithus* peut porter de calcaire. Mais jusqu'en 1951, aucun renseignement valable n'existait sur la vitesse de multiplication des Unicellulaires en mer chaude et profonde, donnée indispensable pour toute approximation sur la masse totale de squelette sécrétée annuellement. Deux sortes de recherches très récentes, et très différentes l'une de l'autre viennent s'appuyer mutuellement pour fournir un permier ordre de grandeur, déjà très utilisable, de cette vitesse.

(a) *Taux de divisions cellulaires moyen* :

D. KRUGER (1949) a suivi jour par jour, durant 4 mois (15 Novembre au 15 Avril) les variations de densité de *Coccolithus fragilis* en surface, à l'extérieur de la Jetée Nord du port d'Algérie. Cette station littorale, exposée aux vents dominants d'hiver, reçoit de l'eau de mer très pure et agitée, où l'abondance des Flagellés calcaires est comparable à celle du large.

L'augmentation maximum observée en 24 heures est d'environ 50% de la valeur de la veille, pour le nombre des *Coccolithus* par litre. Mais un tel accroissement est rare, et les changements habituels sont de 15 à 20% du stock précédent, soit moitié moins que les données obtenues par LOHMANN (1906), près de Syracuse: par des observations quotidiennes, moins suivies, il concluait à un accroissement moyen de un tiers en 24 heures, entre 0 et 50 mètres de profondeur.

E. STEEMAN-NIELSEN (1951) à bord de la *Galathea*, évalue la production organique journalière dans l'Océan. Un échantillon d'eau de mer locale est enrichi en carbone, ajouté sous forme de bicarbonate à base d'isotope radioactif C14. Le flacon est ensuite replacé dans la mer à la profondeur voulue, durant les 12 heures d'éclairement solaire. A la fin, l'eau est filtrée, la radioactivité est examinée sur le filtre à l'aide d'un compteur de Geiger. L'auteur estime que le C14 ainsi retrouvé correspond à la quantité assimilée en 12 heures par les cellules autotrophes du plancton.

En mer chaude et profonde (Océan Indien, de 0 à 100 mètres), le physiologiste danois découvre de cette façon une augmentation journalière de carbone organique d'environ 20%, par temps calme. Or, l'essentiel du phytoplancton local est vraisemblablement constitué par des *Coccolithus*, comme à Alger. Des eaux de l'Océan Indien austral, entre Madagascar et l'île d'Amsterdam, récoltées pour nous à bord du *Commandant Charcot*, avaient, de 0 à 100 mètres, une dominance de *Coccolithus fragilis* aussi forte qu'en Méditerranée.

Cependant, cet accroissement quotidien d'un cinquième est loin de se poursuivre régulièrement toute l'année. L'exemple d'Alger montre qu'il y a souvent des phases d'arrêt ou de recul, surtout par mer trop agitée ou trop calme, l'espèce dominante paraissant adaptée à la petite houle moyenne si fréquente en Méditerranée. D'autre part, après une longue période favorable, les phosphates et nitrates locaux sont épuisés par le phytoplancton et leur rareté freine à son tour la production. En voici une conséquence concrète:

La quantité moyenne de *Coccolithus* par mètre cube d'eau correspond à environ 0,6 g, au large d'Alger, vers 50 mètres. En admettant une augmentation de 1/6 par jour, on aurait près de 2 grammes le huitième jour (valeur assez souvent notée en Méditerranée africaine) et 4,2 g. le 13ème jour. Ce dernier taux est le maximum absolu observé dans cette mer, uniquement dans des eaux exceptionnellement riches du courant atlantique à Nemours (mer d'Alboran, à l'extrême Ouest de l'Algérie)

Donc, en réalité, l'augmentation théorique de 15 à 20% ne se poursuit presque jamais plus de 8 jours, et cette période prospère est souvent suivie d'une égale durée sans multiplication active des Flagellés.

Etant donné ces variations marines, on ne peut donner qu'un ordre de grandeur très approximatif de la fertilité totale annuelle. En Algérie côtière (vers 4 milles au large et entre 25 et 100 mètres de profondeur), *tout se passe comme si* l'accroissement habituel du stock de Flagellés calcaires était de 0,1 g. par mètre cube d'eau et par jour. Cela donnerait, au bout d'un an, un poids de 36 grammes de *Coccolithus*, calcaire compris. L'influence du zooplancton (qui mange ces Flagellés) est déjà entrée en ligne de compte dans notre estimation, puisque seules les cellules intactes sont dénombrées dans les recherches. Il semble d'ailleurs que le poids d'animaux par mètre cube soit généralement bien inférieur à celui du phytoplancton.

En résumé, la cadence moyenne de multiplication des *Coccolithus* est nettement inférieure à celle des Diatomées nordiques, dont le nombre d'individus double en 24 heures en été, d'après les cultures et les comptages déjà publiés . On peut admettre une augmentation journalière de 15 à 20%, dans la couche éclairée des mers chaudes. Mais de nombreuses périodes de stérilité (milieu nuisible ou pauvre en sels nutritifs) alternent avec les périodes fertiles, et, pratiquement, les nombres des cellules connus indiquent une production quotidienne (moyenne annuelle) de 7 à 8% du stock préexistant de la veille, d'où environ 36 grammes de cellules nouvelles par an.

(b) *Production annuelle de calcaire. Chute des Cellules*:

Une plaque périphérique de *C. fragilis* (Fig. 1), appelée *trémalithe*, est en forme de bouton-pression, ses deux disques parallèles étant reliés par un cylindre creux. Considérons une cellule moyenne, ayant un diamètre de 22 μ, coque comprise. Elle porte 178 plaques, se recouvrant légèrement les unes les autres, toutes égales et placées dans la coque gélatineuse externe. J. LECAL (1951) a bien confirmé l'origine endogène de ces plaques, dont chacune apparaît à l'etat mou à l'intérieur du cytoplasme, puis se calcifie et émigre dans la coque).

Chaque trémalithe est haut de 1,6 μ, sa plaque supérieure large de 3,6 μ, l'inférieure de 2,3 μ, leur épaisseur approximative de 0,4 μ. Le volume total de ce Coccolithe est de 3 microns cubes, et c'est un maximum, car le dessin fait pour *Coccolithus huxleyi* par T. BRAARUD, d'après des photographies au microscope électronique (1951), montre de nombreuses rainures parallèles évidées, dans une plaque apparemment pleine au microscope ordinaire.*

Les 178 trémalithes d'une cellule moyenne feraient ainsi 535 microns-cubes de calcaire, soit un peu moins du dixième du volume total du *Coccolithus*, ce qui donne, au plus, 9,7 g. de calcaire pour la production annuelle de *Coccolithus fragilis*, que nous venons d'estimer à 36 g par mètre cube d'eau et par an (large d'Alger).

La densité du protoplasme banal d'un Coccolithophoride doit être légèrement supérieure à celle de l'eau de mer (il n'y a pas ici les gouttes d'huile et les grandes vacuoles qui allègent les Diatomées et les Péridiniens pélagiques). On ignore la densité de la coque gélatineuse qui contient les plaques, mais elle est probablement

* A cette occasion, je remercie mon collègue et ami, T. BRAARUD, Professeur à l'Université d'Oslo, qui a bien voulu communiquer à Mme LECAL et à moi ses résultats inédits, obtenus au microscope électronique.

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faible. Compte tenu des trémalithes, la densité globale de la cellule calcifiée est sans doute supérieure à 1,20.

Cela explique la chute constante vers le fond des stades dépourvus de flagelles (spores, cellules altérées ou enkystées, et surtout amas palmelloïdes, plus gros, dont la masse est beaucoup plus grande par rapport à la surface externe). Seuls les courants horizontaux ou ascendants, ou des couches de viscosité maxima (comme paraît être la couche de 300 à 500 mètres en Méditerranée) peuvent arrêter cette chute ou la ralentir, mais tôt ou tard le calcaire produit atteindra plus loin le fond marin.

4° SÉDIMENTATION THÉORIQUE ET SÉDIMENTATION RÉELLE

Supposons, au large de la baie d'Alger, une colonne d'eau de 100 mètres de hauteur et un mètre carré de section, où la production serait uniformément de 36 grammes de *Coccolithus* par mètre cube et par an. Il se déposera sur le fond, au maximum, 970 g de calcaire. En admettant 50% d'eau d'interposition dans le sédiment frais (taux habituel trouvé par PETTERSSON 1948, en Méditerranée) et pas d'autres éléments solides que les coccolithes, cela donne une épaisseur de dépôt de 570 millimètres en mille ans.

Ce raisonnement simpliste aboutit à un taux de sédimentation 6 à 10 fois plus grand que les taux réels. D'abord, les travaux de PETTERSSON, déjà cités, dont plusieurs ont eu lieu au large d'Alger, indiquent seulement 20 à 35% de calcaire dans les vases côtières locales, le reste étant surtout formé d'argile et de sable. Une portion de ce calcaire étant due aux Foraminifères et aux Mollusques, la part probable des Coccolithophorides dans la vase méditerranéenne ne doit guère dépasser 15% de son poids frais, eau d'interposition comprise. Ensuite, SVERDRUP (1946) estime l'épaisseur de sédiments nouveaux entre 140 et 680 mm par 1.000 ans pour les couches néritiques, entre 5 et 33 mm pour la zone pélagique très loin des côtes. Supposons, au large d'Alger, entre la baie et la zone pélagique, un taux de 50 à 150 mm. Notre évaluation initiale est beaucoup trop forte.*

Conclusion: la très large majorité des coccolithes formés en un an par le phytoplancton (au moins 95 à 97% de leur masse totale) échappent à la sédimentation. Ces plaques très minces (0,3 μ à 0,4 μ d'épaisseur chez *C. fragilis*) doivent être dissociées et dissoutes avant d'atteindre le fond, et, dans le sédiment lui-même, l'action des Bactéries et des mangeurs de vase doit continuer sur les coccolithes présents. D'ailleurs, peu de trémalithes entiers de *Coccolithus fragilis* sont reconnaissables dans les vases d'Alger et de Monaco mais il leur correspond, presque certainement, la plupart des granules et lozanges de calcite formant l'essentiel du calcaire indéterminable déposé là, de 50 à 2.000 mètres et plus. Dans la baie d'Alger, en effet, j'ai pu trouver tous les intermédiaires entre un trémalithe complet, intact, des fragments de plaques plus ou moins lozangiques et des granules arrondis de 2 μ et moins. Cette décomposition en granules parait toujours se faire aved l'aide de Bactéries, attaquant d'abord la coque gélatineuse, puis les coccolithes qu'elle renferme.

Les plaques de *Corisphaera fagei* (Fig. 1, *f*), des gros *Syracosphaera* et des grands *Coccolithus* (Fig. 1, *g*; *h*) se conservent mieux dans les vases, étant 2 à 6 fois plus

* Grâce aux ultra-sons, PETTERSSON et WEIBULL (1947) trouvent au large d'Alger, par 2.300 m. de fond, une épaisseur totale de sédiments voisine de 300 mètres. Or, les géologues pensent que les rivages de l'Algérie ont pris leur forme actuelle au Miocène, il y a environ 3 millions d'années. Cela donne justement 100 mm en mille ans.

épaisses que celles de la forme dominante *C. fragilis*. Plus résistantes encore sont les plaques de Flagellés fossiles, provenant des terrains miocènes et pliocènes du littoral algérien, ou amenées de loin par les cours d'eau. Le fond de la baie d'Alger est ainsi parsemé de coccolithes géants, appartenant notamment à des *Coccolithus* miocènes, inconnus jusqu'ici dans les mers actuelles. Mme LECAL-SCHLAUDER décrira prochainement ces fossiles variés.

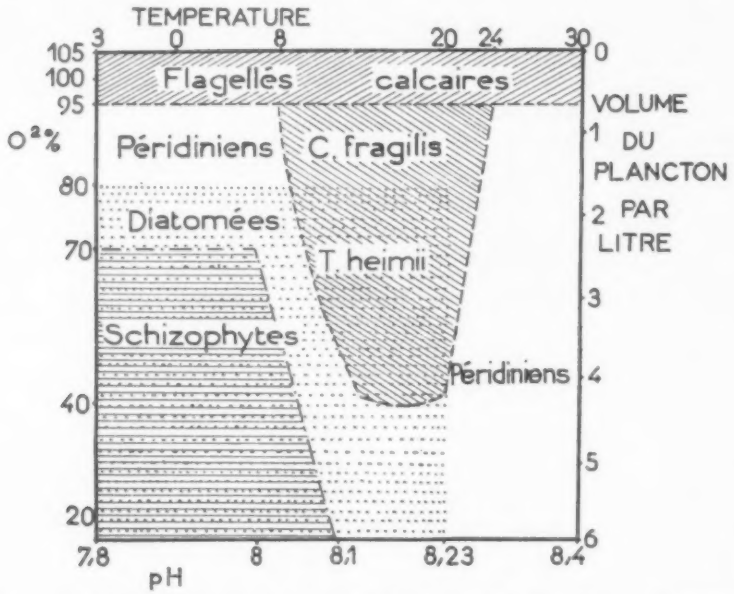

Fig. 3. Diagramme résumant les conditions générales de prépondérance des principaux groupes de phytoplancton, de 0 à 1.000 mètres, surtout d'aprés les résultats du *Meteor* (HENTSCHEL, WATTENBERG et WUST, 1936) dans l'Atlantique, recombinés ici avec ceux de F. BERNARD au large de Monaco et d'Alger.

En moyenne, la teneur en oxygène (figurée à gauche en por cent de la valeur de saturation), varie en sens inverse de la richesse en plancton (notée schématiquement à droite, de 0 à 6). Les Flagellés calcaires (en hachures obliques) ne dominent sur les autres groupes que dans des eaux très riches en O_2, sauf pour *Coccolithus fragilis* et *Thoracosphaera heimi*, espèces bathypélagiques. Au-dessous d'une température de + 8° centigrades, seuls *Th. heimi* et *Coccolithus huxleyi* se montrent capables de pulluler.

Les Diatomées (en pointillés) et Schizophytes (*Nostoc* et *Microcystis*, en hachures horizontales) ont des optima presque opposés à ceux des Flagellés calcaires.

Enfin, les Péridiniens dominent dans les milieux défavorables aux trois autres groupes et sont les principaux concurrents de *Coccolithus fragilis* dans les mers tropicales, ou ils paraissent mieux supporter le soleil et la chaleur que les *Coccolithus*.

5° REMARQUES SUR L'ÉCOLOGIE DES FLAGELLÉS CALCAIRES

Peu d'Expédicions océanographiques ont récolté du nannoplancton, et moins encore ont étudié simultanément les principaux facteurs mesurables de la vie marine: température, salinité, *p*H, oxygène, phosphates, etc. C'est pourtant le cas durant les recherches de STEEMANN-NIELSEN au large de l'Islande et du Groënland (1935), celles de GRAN et BRAARUD dans la baie de Fundy (1935) et surtout celles de HENTSCHEL à bord du *Meteor*, dans l'Atlantique sud (publiées en 1936). En Méditerranée,

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ERCEGOVIC (1936) a observé l'Adriatique au large de Split, et j'ai suivi le cycle annuel du phytoplancton près de Monaco, de Banyuls (1936-39) et dans les parages de A'lgérie depuis 1945.

Tout celà ne concerne qu'une partie de l'Atlantique et de la Méditerranée, mais il est fort probable que les besoins de milieu de chaque espèce dominante, sont les mêmes dans toutes les mers, au moins pour les conditions limites de reproduction. Quant au milieu optimum, permettant une grande abondance numérique (plus de 100.000 cellules par litre chez les *Coccolithus*, par exemple), il varie au contraire selon les principales régions marines. En voici un cas typique:

Parallèlement à mes travaux au large d'Alger, G. TROTET dénombre les Flagellés et Péridiniens près de Tanger (Maroc), et trouve pour *Coccolithus fragilis* la même dominance quantitative qu'en Algérie. Or, les eaux de Tanger, zone atlantique peu profonde, balayée par d'intenses courants de marée, offrent des conditions physico-chimiques très différentes de celles de la Méditerranée (notamment salinité, *p*H et oxygénation plus bas, agitation et teneur en Bactéries beaucoup plus fortes). Donc, la race locale de *Coccolithus*, s'est bien adaptée à ce milieu troublé, tandis que l'optimum de celle d'Algérie correspond à la petite houle moyenne, avec eaux transparentes et très oxygènées, qui est le régime habituel durant les deux tiers de l'année. Mais le contraste accentué entre Alger et Tanger ne doit pas cacher les caractères communs à ces deux régions: climat subtropical très humide, températures marines entre 12 et 26°, éclairement solaire fort. Ces conditions suffisent à faire prospérer une forme assez indifférente à l'agitation et à l'oxygénation, comme *C. fragilis*. A ce type biologique s'opposent bien d'autres, tels que ceux des Dinoflagellés *Exuviella* et de certaines Diatomées, pullulant à Tanger mais rares en Algérie: pour ces Protistes, l'agitation et la richesse en substances organiques doivent être nécessaires.

Loin des côtes, les milieux varient moins d'une mer à l'autre, et l'ensemble des Expéditions déjà citées m'a permis une reconstitution des limites écologiques pour les principaux groupes du plancton unicellulaire (F. BERNARD, 1942). La Fig. 3 ci contre est un résumé de ces resultats, un peu schématique mais mettant en valeur les conditions de pullulement des grandes catégories du phytoplancton, dont les exigences respectives se dégageaient mal des tableaux numériques détaillés des précédents auteurs. En voici un bref commentaire:

Si l'on excepte les formes bathypélagiques, la presque totalité des Flagellés calcaires (145 espèces sur 150) abondent en eaux très oxygènées (95 à 105% de la saturation), ces eaux bleues (type *oligotrophe* de HENTSCHEL) sont en même temps pauvres en plancton total. Certains Coccolithophorides (surtout *Coccolithus huxleyi* et *pelagicus*) tolérent des mers froides, agitées et à *p*H souvent bas, mais la majorité de l'ordre vit au dessus de + 9° et d'un *p*H égal à 8,1.

A ce groupe s'opposent de façon frappante les Diatomées, et plus encore les Myxophycées ou Cyanophycées (" Schizophytes " de la Fig. 3), qui dominent à moins de 80% de la saturation en 0_2 et au dessous de 20°, dans un plancton dense ou assez dense (type *eutrophe* de HENTSCHEL). Ces Algues sont donc rares en Méditerranée (trop oxygènée pour elles) et ne font que 5 à 12% de la moyenne annuelle du nanoplancton d'Alger. Les Péridiniens font office de " bouche-trou ": ils ne l'emportent en volume relatif que dans les mers chaudes riches en plancton (donc nuisibles aux Flagellés calcaires, c'est le cas de l'Atlantique africain dans une

bonne partie de son domaine), plus rarement dans les eaux froides mais riches en oxygène (alors défavorables aux Diatomées).

Considérons, pour terminer, le type spécial des quelques Coccolithophorides de grande profondeur. Ils habitent souvent des couches relativement pauvres en oxygène (40 à 80% de la saturation) et assez froides (8 à 12°). Les spores et kystes de *Coccolithus fragilis*, et surtout les cellules actives de *Thoracosphaera heimi*, abondent dans des eaux encore plus froides (+ 3 à + 8°) ce qui leur permet de descendre jusqu'a 4.000 mètres et probablement plus bas.

Ces êtres font généralement plus de 50% du volume local moyen de phytoplancton, le reste des Algues bathypélagiques étant essentiellement constitué par des Cyanophycées (*Nostoc*, *Microcystis* et genres voisins, correspondant aux " Olivgrün zellen " de HENTSCHEL). Il y a donc lieu, non seulement d'accorder de l'importance aux Flagellés calcaires dans la sédimentation abyssale, mais avant tout de les considérer comme une source de vie et de nourriture essentielle dans les couches profondes des mers chaudes et tempérées du globe.

Algiers.

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Deep-Sea Research, 1953, Vol. 1, pp. 47 to 59. Pergamon Press Ltd., London.

The significance and diatom content of a deep-sea floor sample from the neighbourhood of the greatest oceanic depth

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Summary—A unique sample collected by H.M.S. *Challenger* about five miles away from the greatest known oceanic depth in the Marianas Trench has been presented to the British Museum (Natural History). The systematics of the diatom *Ethmodiscus rex* are discussed. There is clear evidence of erosion in photographs taken by the electron microscope. The geomorphological relations, as well as some of the problems of deep-sea trenches, are discussed.

INTRODUCTION AND GEOMORPHOLOGICAL RELATIONS

THROUGH the kindness of Vice Admiral A. Day, the Hydrographer of the Navy, the British Museum (Natural History) has been given a unique sample (Min. dep. 1952, 35 (1)) of the deep-sea floor collected by H.M.S. *Challenger* about five nautical miles away from the greatest oceanic depth (CARRUTHERS and LAWFORD, 1952; GASKELL, *et. al.* 1953). This sample, preserved in alcohol and filling about one third of a pound jar, was taken by means of a Baillie rod at a depth of 5744 fms. (10,505 m) at 11° 20.0′ N 142° 19.0′ E. This trench is one of a series, roughly defined by the 3500 fms. (6400 m) contour, extending in a southerly direction from Japan to the Palau Islands (Fig. 1).

The Marianas lie on the eastern branch of a ridge extending from the Izu Peninsular, southwest of Tokyo Bay, in a southerly direction to approximately 12° N 142° E (TAYAMA, 1936; TANAKODATE, 1940; HESS, 1948; TAYAMA, 1952). This ridge, called the South Honshu Ridge, by the British National Nomenclature Committee, rises some 6000 ft. from a general depth of 2000 fms. (3658 m). There are many seamounts on this ridge and in its northern part form volcanic islands. South of Iwo Jima, in the Kazan Is., the ridge bifurcates. The eastern ridge, known as the Marianas Ridge (Fig. 2), extends from approximately 22° 30′ N 142° 50′ E to 12° N 144° 30′ E. The Marianas Ridge rises some 6000 ft. from a depth of 2000 fms. at its western base, whilst its eastern base is the bottom of the Marianas and Bonin Trenches. Nine volcanic islands rise some 5000-6000 ft. from the Marianas Ridge: Farallon de Pajaros, Maug, Asuncion, Agrihan, Pagan, Alamagan, Guguan, Sarigan, Anathan. Volcanic eruptions when they occur are either relatively quiescent lava flows or explosive, as in the case of Agrihan or Asuncion where abundant ash and ejecta are emitted. The volcanic rocks are either basalts or basic andesites, whereas the rocks of Iwo Jima, one of the nearest active volcanoes on the South Honshu Ridge, are acedic andesites or trachyandesites with silica ranging from 58.9 to 60·8 per cent.

East of the volcanic axis (Fig. 2) is an outer chain of islands from Farallon de Mednilla to Guam consisting of tertiary limestones and bedded volcanics. Terraces tilted towards the west are common on the Southern Mariana and HESS (1948, p. 451) has suggested that the westward tilting has been accompanied by an eastward shift of the geanticlinal axis. In the north where the terraces are not tilted the geanticlinal and volcanic axes converge to form a single axis.

Fig. 1. The main deep-sea morphological features in the Phillipine—Marianas region.

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DEEP-SEA HYDROGRAPHY

Through unfortunate accidents involving the loss of several lengths of hydrographic wire only one deep-sea water sample was collected in the Marianas Trench by H.M.S. *Challenger*. This was secured by attaching a water bottle to the thin sounding wire. The water sample, sent to the British Museum (Natural History), was from a depth of 5359 fms. Chlorinity was determined using silver chloride-calomel electrodes and a Cambridge valve potentiometer. Two determinations gave 19·262, 19·263 °/₀₀, corresponding to a salinity of 34·73 °/₀₀. The temperature was 2·2°C. The salinity of the surface water at a nearby station (11° 13.5′ N 142° 9.5′ E) is 34·36 °/₀₀ (UEMURA, 1933 p. 62).

SYSTEMATICS OF DIATOMS

The deposit is brown when wet. About 4 per cent, consisting essentially of diatoms and minor amounts of radiolaria, is coarser than 63 μ. A little volcanic debris, as well as a few ovoid bodies suggestive of fæcal pellets are present. Only one species of diatom is present which was identified as *Coscinodiscus rex* Wallich. RATTRAY's (1890, p. 568) description is as follows:—

> " C. *rex*. Wallich, Jour. Roy. Micr. Soc. Lond. 1879, p. 688 – Diam. 1·25 to 1·4 mm. Central space and rosette absent, but an indistinctly defined central area, with round isolated granules and hyaline interspaces, as well as distant irregular, somewhat curved large apiculi, evident. Markings on the central area without order, beyond this area round, forming straight closely disposed radial rows, 3 in. ·01 mm; on the sides of the cylindrical valve the rows straight, and corresponding in position to those in flat surface of valve, but the markings smaller, 5 in. ·01 mm; central papillæ prominent ; a circular smooth space sometimes present at junction of terminal and lateral portions of cylindrical valve – Sch., *Atl.*, pl. cxiv. fig. 7; C. *regius*, Grun., *Jour. Roy. Micr. Soc. Lond.*, 1879, p. 688.
>
> This species was originally distributed under the name of C. *rex*.
>
> *Habitat* – Bay of Bengal (Wallich, 1857; Kitton!); H.M.S. *Challenger*, Stat. 265, 2900 fathoms (Grunow); Nancoori (Cleve!)."

Earlier references to this diatom are somewhat vague, RATTRAY, in the above, accredits the name *Coscinodiscus rex* to WALLICH, but the reference cited (GRUNOW and KITTON, 1879) is a translation of GRUNOW's (1878) paper. RATTRAY also gives *Coscinodiscus rex* as synonymous with *Coscinodiscus regius* Grunow, citing the same paper. KITTON's note (GRUNOW and KITTON, 1879, p. 689) regarding this is not very illuminating; it reads as follows:—

> *C. Gazellæ* Janisch – Diameter of valve (as far as can be ascertained from fragments), 1·8 to 1·9 mm, thus exceeding even *C. regius* in size. Centre smooth, like *C. nobilis*, but bordered by a circle of small spines similar to those occurring in *C. regius*; the radiating rows of puncta are somewhat closer than those in that species (6-7 in ·01 mm.). Upper edge of valve smooth, precisely as in *C. regius*. Near the margin numerous short irregularly curved striæ (consisting of darker puncta) are visible.
>
> ' Gazelle ' sounding, No. 125, 30°53′ S. lat., 177°6′ E. long.; depth 4151 m. ' Challenger ' sounding, station 265, depth 2900 fathoms. This form was named by Herr Janisch in remembrance of the scientific expedition made by the German ship, ' Gazelle,' in the years 1874-1876. Pl. XXI, Fig. 8 (450/1).
>
> I have found fragments that can only belong to this species in a sample of Nottingham deposit in which it was not uncommon.*

* KITTON is here describing *Coscinodiscus gazellæ Janisch*, and his comparisons of that species with *C. regius* and *C. nobilis* cannot be accepted as valid descriptions of the two latter species.

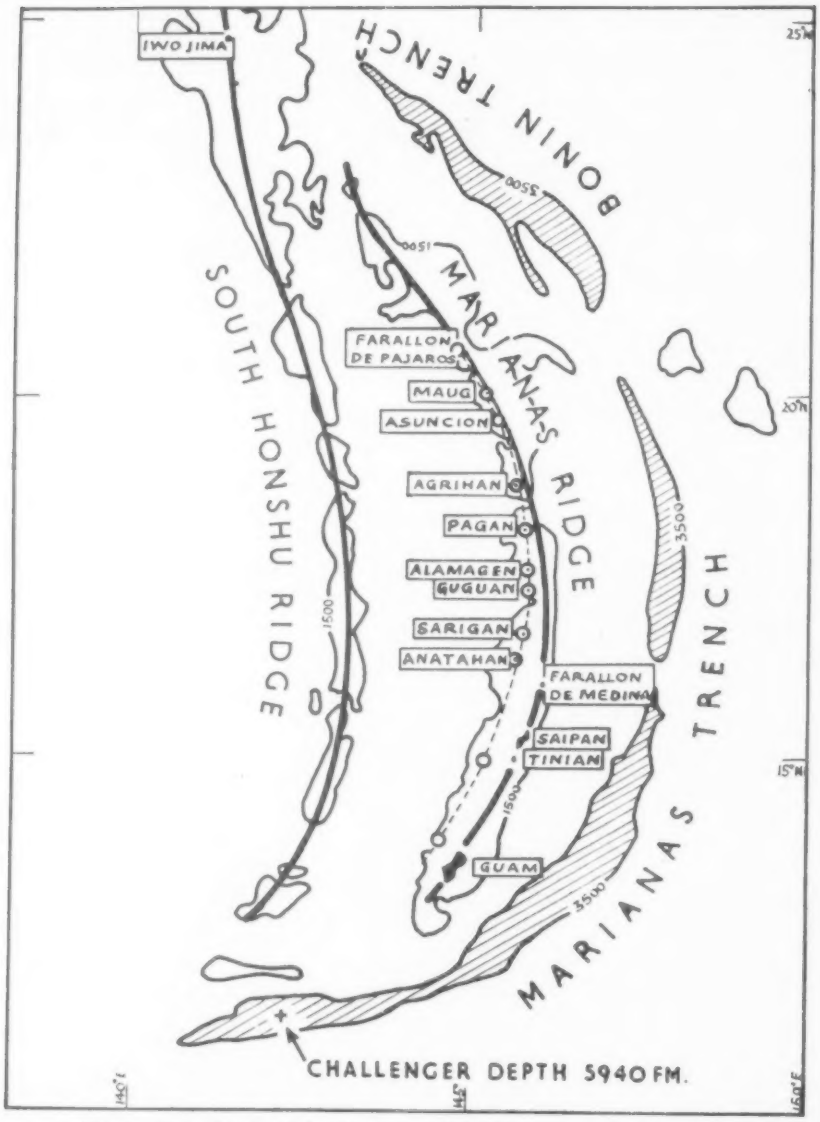

Fig. 2. The relation of the *Challenger* depth to neighbouring features.

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" *C. regius* was originally distributed under the MS. name of *Rex*. It is undoubtedly the largest diatom, excepting *C. gazellæ*, hitherto discovered. *C. regius* was first found, in the Bay of Bengal in 1857, by Dr. Wallich. The lighter portions of one of the ' Challenger ' dredgings (station 265, depth 2900 fathoms) consist almost entirely of fragments of this species."

The earliest use of the name *Coscinodiscus regius* appears in the Proceedings of the Royal Microscopical Society for March 11, 1868 (*Quart. J. Micr. Sci.*, 1868, p. 115). The name was mentioned in the discussion that followed the reading of a paper by COLLINGWOOD (1868).

On p. 115 of the *Quarterly Journal of Microscopical Science* (1868) it is stated that " The *Cocscinodiscus* referred to, and which has been described and figured by Dr. WALLICH under the name of *C. regius* is probably the largest known diatom, the frustule measuring 1/20th an inch in diameter. Like the minute tufts already spoken of, it was met with in countless myriads, during calms, in the Bay of Bengal." On the previous page (p. 114) it was reported that " Dr. WALLICH was fully able to confirm the valuable observations of Dr. COLLINGWOOD having had opportunities of examining and figuring the organisms referred to during voyages to and from Bengal, in the years 1851 and 1857." The second date given here, 1857, is that noted by KITTON and quoted above. It appears that at no time did WALLICH validly publish the name *Coscinodiscus regius*, and the description and figure mentioned in the *Proceedings of the Royal Microscopical Society*, 1868, p. 115, refers to the manuscript notes and drawings which accompanied WALLICH's collection of 1031 slides donated to the Royal Microscopical Society on January 8, 1868, and generously acknowledge by GLAISHER (1868) in his Presidential Address. This collection of slides contained specimens of the diatom referred to, bearing the manuscript name *Coscinodiscus regius*.

Neither the slides nor the manuscript notes and drawings appear to be in the collections of the Royal Microscopical Society today. The name *Coscinodiscus regius* Wallich must be treated as a *nomen nudum*, and the earliest validly published name, accompanied by a description and illustration to which the specimens from the Marianas Trench can be referred is *Coscinodiscus rex* in RATTRAY (1890, p. 568).

The true taxonomic position of the specimens from the Marianas Trench is not at all easy to determine. The genus *Coscinodiscus* is very large and some authorities recognise divisions and separate genera within it not accepted by others. The genus *Ethmodiscus* created by CASTRACANE (1886) in the report of the diatoms of the *Challenger* voyages is, however, well founded, and after consultation with Dr. R. W. KOLBE of the Naturhistoriska Riksmuseum, Stockholm, who is interested in this and similar species from the long cores collected in the Pacific Ocean by the Swedish Deep-sea Expedition 1947-48, one of the authors (N.I.H.) has no hesitation in making the new combination *Ethmodiscus rex* (Rattray), and provides the following description.

Ethmodiscus rex (Rattray) Hendey

Coscinodiscus rex Wallich in Rattray (1890 p. 568 (120)).
Coscinodiscus rex in Schmidt's Atlas (1888 pl. 114, fig. 7 (fragment only))
Coscinodiscus regius Wallich in Kitton (1879, p. 688) (*nomen nudum*)
Ethmodiscus sp. indet. Hanzawa (1933, p. 42, pl. 1. 2.)

Valves circular, 1·7 to 1·9 mm in diameter, valve surface almost flat, or very slightly convex at a distance equal to half the radius. Marginal area flat, valve mantle sudden, deep. Valve margin furnished with a narrow hyaline band. Valve surface

ornamented with straight radiating lines of small holes, 3 in 10 μ, each about 1 μ in diameter. The holes, or puncta, towards the valve margin and on the valve mantle, are slightly closer together, and often a little smaller, 5 in 10 μ. Often narrow hyaline areas radiate between the lines of holes. Central area and rosette absent, but the regularity of the lines of holes gives way to a more open or irregular arrangement often in whorls, at a distance equal to about quarter of the radius. In this open central portion of the valve larger elongated or reniform holes appear, which are associated with short, curved, tubular formations, 10-12 μ long. These tubes appear as thickenings or tunnels in the silex of the valve itself. There are usually 30-50 of these tubular structures on each valve surface.

Girdle deep, of the " sprung " or discontinuous type, furnished with straight parallel lines of holes, 5 in 10 μ, margin of girdle furnished with clear, hyaline bands, 10 μ wide on the lower and about 3 μ along the upper margin. The wider hyaline margin is continued around the adjacent ends of the " sprung " girdle. At these ends the lines of holes appear to be flared at the lower corners, that is, adjacent the wider hyaline borders. Each girdle is from 200-220 μ wide.

The material consisted mostly of fragments, the girdle breaking up into pieces which were mainly rectangular. The pieces varied considerably in size, although no extremely small fragments were present. The sizes of the fragments varied from 6,000 μ^2 to 62,000 μ^2. The valve broke up into fragments of two types, fragments of the centre area showing the whorls of puncta, and those of the marginal area suggesting that the slight undulation that usually separates these zones may be also a line of strain or weakness.

Quite a large number of whole valves were present, which made it possible to provide a complete description of the organism. The tubular structures in the central part of the valve are unusual, as no other species in the family *Coscinodiscaceæ* is known to possess them. Their true function is not known. They may serve some physical purpose by linking or holding contiguous cells together, but more likely, may be special structures from which mucous threads are exuded.

It is interesting to note that the position from which this material was recovered, is close to Station No. 225 made by H.M.S. *Challenger* during her classical voyages of 1872-76. On 23 March 1875 a sample of the deep-sea floor was taken at 11° 24.0′ N 143° 16.0′ E from a depth of 4475 fms. (8185 m), that is, about 60 nautical miles east of the 1951 station. Microscopical examination of this earlier material in the collections of the British Museum (Natural History) (M 289) showed that it was similar, but not the same as, that collected in October 1951. The material was

PLATE 1

Ethmodiscus rex

Fig. 1. Central area of valve showing tubular structures surrounded by sub-circular hyaline areas, and irregularly arranged puncta, and the beginning of the radial striae (× 300).

Fig. 2. Girdle material showing wide hyaline margin and parallel striation. Note granular appearance due to solution of silica (× 1000).

Fig. 3. Girdle material, showing corner with narrow hyaline margin on one side and wide margin on the other (× 900).

Fig. 4. Edge of valve showing narrow hyaline margin (× 1100).

Fig. 5. Tubular structure through the valve, probably a mucus secretory organ showing elongated aperture on the upper surface, and truncated, probably capped, lower or inner end (× 2350).

Fig. 6. Same as Fig. 5, showing breakdown of tubular structure due to advanced state of silica solution (× 2350).

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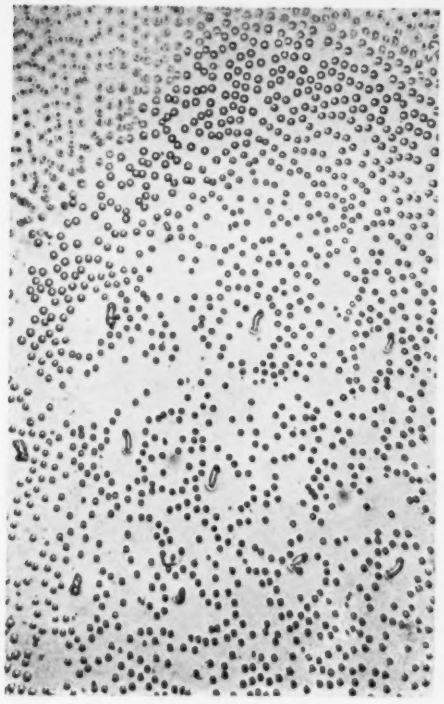

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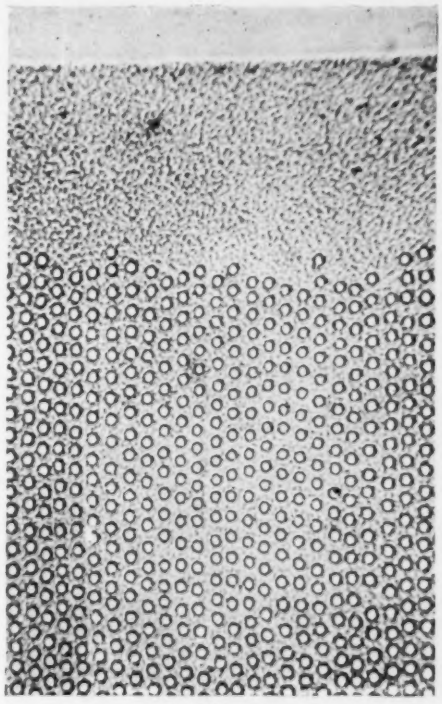

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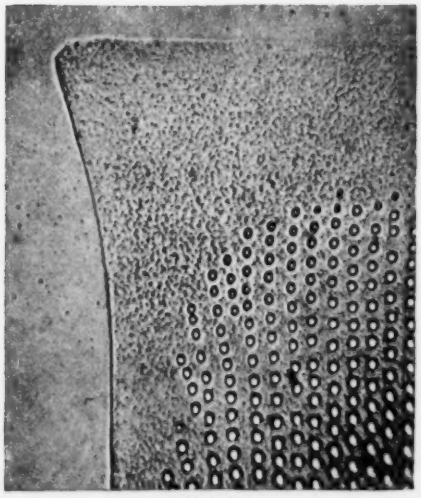
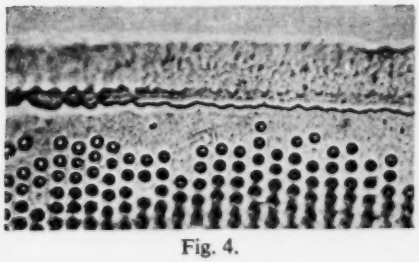


Fig. 3.

Fig. 5.



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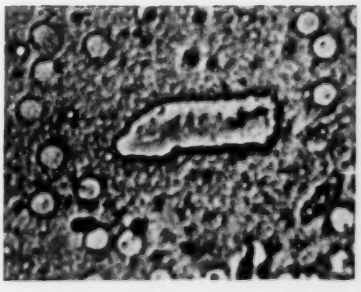

Fig. 6.

PLATE 1

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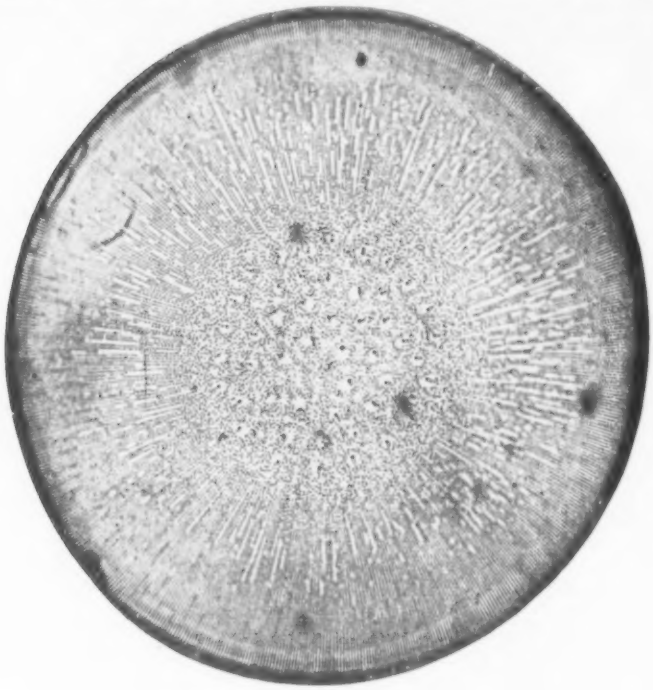

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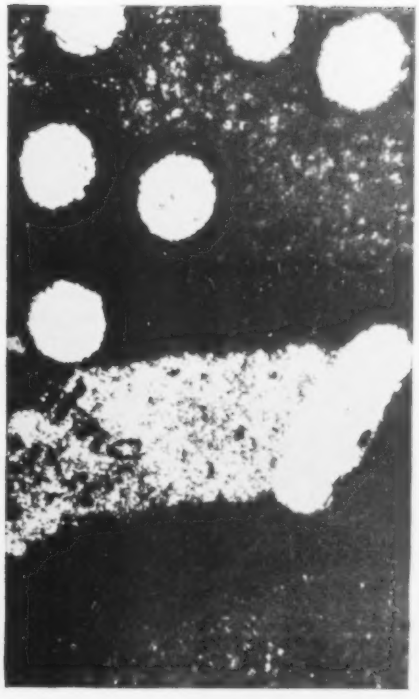

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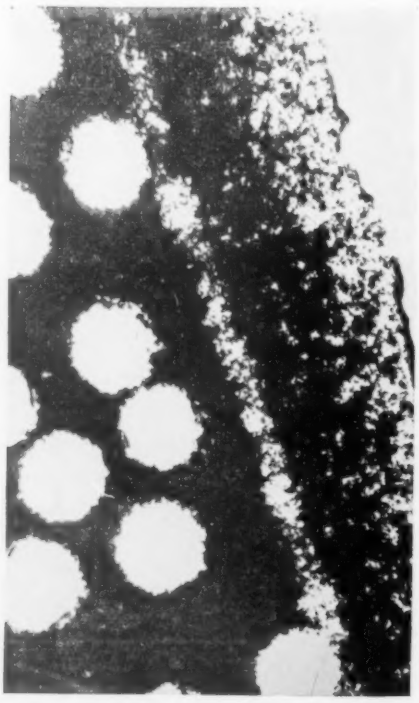

Fig. 3.

PLATE 2

Note: The above reproductions are half the original size.

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similar in colour, and about the same proportion of it was organically produced silica. The chief difference was, however, in the proportions of the organisms represented. The earlier material was almost entirely composed of radiolarians with very few diatom fragments. The fragments undoubtedly belong to the same species, *Ethmodiscus rex*. The identification rests upon fragments of the central portion of the valve, showing the scattered curved tube-like structures.

The formation of deposits of *Ethmodiscus rex* on the floor of the ocean, apparently concentrated in a relatively small area, provides many interesting problems. Very seldom has *Ethmodiscus rex* been found in the living state in plankton. There is no indication that the species is found living in the waters immediately over the deposit itself. Commander G. S. RITCHIE R.N., who was in command of H.M.S. *Challenger* during the 1950-51 cruise, kindly sent one of the authors (N.I.H.) the sample of plankton which was taken nearest to the deepest sounding. The details are as follows. Sample No. 136, 6° 43′ N 143° 27′ E sea surface temperature 29°C, taken at the surface with a fine plankton net. This sample contained no specimens of *Ethmodiscus rex*. A far more intensive study of the plankton of the Pacific Ocean will have to be made before the distribution of *Ethmodiscus* species is fully known. It is likely that *Ethmodiscus rex* swarms suddenly, and in enormous numbers during calm periods within certain prescribed areas, and that its vegetative season is very short. This would account for the fewness of the records in the plankton.

HANZAWA (1933) describes diatom ooze collected from areas in the tropical Pacific Ocean by Japanese ships between 1926 and 1933. This author did not identify the species, but from his plates (which are not especially good), particularly from Plate 2, fig. 1, there is little doubt that his material consisted chiefly of *Ethmodiscus rex*. HANZAWA states (p. 39) that " The localities of the Diatom Ooze with abundant *Ethmodiscus* known up to the present lie between latitudes 19° 08.5′ N-8° 40.0′ N and longitudes 136° 22.6′ E-153° 06.5′ E, and seem to occupy only relatively small separate areas, as they are interrupted by areas of *Globigerina* Ooze and Red Clay – the bathymetrical range of the Diatom (*Ethmodiscus*) Ooze is from 2780 m to 5714 m, average being 4205 m ".

Although the area specified includes the deep sounding made by H.M.S. *Challenger* in October 1951, HANZAWA's important observation requires some amplification.

It is not at all clear at the moment how many species of *Ethmodiscus* can be recognised. CASTRACANE (1886) first created the genus *Ethmodiscus*, and described 13 species, others have been added by PANTOCSEK, AZPEITIA and KARSTEN. HUSTEDT (1927-30, p. 375) reduces five of CASTRACANE's citations to the synonymy of *Ethmodiscus gazellæ* (Janisch) Hustedt. Bearing in mind that HUSTEDT does not provide an original illustration, but only copies of CASTRACANE's and PAVILLARD's rather poor drawings, none of which shows the definitive characters of the valve surface of the species, it would be unwise to place too much stress on the matter until the

PLATE 2

Ethmodiscus rex

Fig. 1. Valve view of organism (× 150).

Fig. 2. Electronmicrograph of valve surface showing breakdown of siliceous mucus tube (× 10,000).

Fig. 3. Electronmicrograph of girdle fragment showing breakdown of silica, probably by solution (× 10,000).

The electronmicrographs were prepared by F. W. CUCKOW, Esq., Chester Beatty Research Institute, Royal Cancer Hospital, London.

type material can be critically examined by modern methods. Sufficient is clear, however, to say that *Ethmodiscus rex* (Rattray) is quite distinct from what is generally known as *Ethmodiscus gazellæ* (Janisch) Hustedt and that the former has a more restricted distribution. *Ethmodiscus gazellæ* (Janisch) Hustedt is known to have a wide distribution in the south-western Pacific Ocean, and its presence has been reported in the plankton of the Mediterranean. While it seems certain that deep sea oozes of *Ethmodiscus Gazellæ* have been found in the south Pacific and perhaps elsewhere, *Ethmodiscus rex* (Rattray) appears to be confined to the north Pacific Ocean. The area circumscribed by HANZAWA (1933), may require a certain amount of modification in the light of the soundings made by the U.S. cable survey ship *Nero* (MANN, 1907), which suggests that the *Ethmodiscus rex* ooze stretches in an east west direction for a distance of about 3,000 miles within the limits of latitude expressed by HANZAWA.

It is difficult to follow HANZAWA and speak of a bathymetric range of a diatom ooze as though it possesses some specific significance. Inert silica fragments of dead organisms will sink to the lowest possible level. That recovered by H.M.S. *Challenger* in October 1951 was from the neighbourhood of the deepest sounding ever made, in the Marianas Trench, at a depth of 5744 fms. (10505 m). At that depth the pressure is of the order of a thousand atmospheres, or about 7·5 tons to the square inch. No data is available of the acceleration of the solution rate of silica at this great pressure, but the diatom fragments from the Marianas Trench material have strong evidence of wear and tear, which could be interpreted as erosion or solution. While the former cannot be ruled out completely, sharp angles on most of the fragments indicate that erosion is not the major factor operating. The general or overall thinness of the diatom silica is shown in the plates provided, and is particularly clear in the electron micrograph (Pl. 2, figs. 2 and 3) kindly prepared by Mr. F. W. CUCKOW of the Chester Beatty Research Institute. It indicates a more or less uniform attack produced by the solution of the silica in the sea water.*

This brief note about the diatoms could not be terminated better than by including the following quotation from MANN (1907):—

> " In the cable survey of the U.S. steamer *Nero* a series of soundings was made over a long belt of sea bottom between the islands of Guam and Luzon which I find are full of the gigantic *Coscinodiscus rex* Wallich, a diatom by no means common, but found here in such enormous, quantities that the gatherings are often a pure siliceous mass of the remains of this one species. This belt is over 3,000 miles long east and west and of unascertained width, perhaps 20 miles or a little over. On the return voyage whenever the ship's course entered this belt great quantities of this diatom were again secured. Thus, for example, at survey station 746, latitude 14° 24′00″ N, longitude 135° 31′00″ E, 2,788 fathoms, the material is practically pure *Coscinodiscus rex*. Unquestionably such enormous quantities of this single diatom must have been transported to this belt of sea bottom by long-continued and constant currents; and it would therefore be quite possible, by the study of soundings and especially of surface gatherings made in the future, to determine the origin of this vast supply and consequently the trend and extent of the transporting current."

The geographic range of *Ethmodiscus rex* is not yet fully known, but it is likely to be more widespread than was at first thought. Recently, in a private communi-

* It is to be noted also that the puncta or holes through the diatom valve do not show any secondary structure, such as an inner plate with fine perforations. This is unusual for the *Coscinodiscacæ*, particularly as the holes are relatively large (about 1 μ in diameter). The intimate structure of *Ethmodiscus rex* in the living state is not known, but if the puncta are normally furnished with an inner perforated plate, this structure being weakly siliceous has dissolved.

cation, Dr. R. W. KOLBE of Stockholm, has informed one of the authors (N.I.H.) that during an examination of an Atlantic core recovered by the Swedish Deep Sea Expedition 1947-48 *Ethmodiscus rex* was the dominant species. The core was taken at 5° 45′ N, 21° 43′ W from a depth of 1956 fms. (3577 m). The diatom-bearing layer was at a depth of 793 cm.

PROBLEMS OF DEEP-SEA TRENCHES

The problems concerning deep-sea trenches are important, because it is unlikely that a correct synthesis of the ocean basins can be formulated until more is known about them. It is therefore not out of place to discuss briefly these problems.

The natural sedimentary sequence in long undistorted cores from deep-sea trenches would doubtless reveal their most recent history. From investigations on cores it might be possible to correlate eruptions of known age with volcanic layers. For work of this nature it is essential that cores should be collected at localities unaffected by slumping or turbidity currents. The chemical interchange – evident from the corrosion of the diatoms – between the bottom water and the sediment requires detailed investigation. The possibility that in the Puerto Rico Trench sedimentation is in places the result of turbidity currents has been stressed by ERICSON, EWING and HEEZEN (1952, p. 496). Attempts should be made to detach portions of the solid rock from the sides of trenches to secure information about its nature below the sediment carpet. Fragments from the sides of neighbouring seamounts would be specially significant if they contained fossils. The island arcs associated with many deep-sea trenches give useful geological information, and where sediments occur their thickness should be determined by seismic refraction methods.

The sedimentary thickness on the trench floor should be determined by seismic refraction surveys. In the Puerto Rico Trench there is apparently a great thickness of sediments, as EWING reports that attempts to measure it have so far failed (HILL, 1953, p. 858). The thermal gradient should also be measured, and magnetic surveys using a towed magnetometer would give useful information. Gravity measurements, as shown by the pioneer work of VENING MEINESZ (1934), are of the greatest importance. In the Puerto Rico Trench it has been concluded that a thickness of 9 km of sediments is sufficient to satisfy the gravity field, and that there is no deep root of lighter rock, as required by the VENING MEINESZ theory of the formation of geosynclines (HILL, 1953, p. 858). The results of the gravity survey in the Pacific Ocean, especially the circum Pacific earthquake belt (WORZEL and EWING, 1952, p. 457-459) will doubtless be an important contribution. The study of earthquake epicentres is significant (GUTENBERG and RICHTER, 1949).

Detailed topographic surveys should be made of selected portions of deep-sea trenches, and areas where the bottom is perfectly flat should be delineated. It is probable that in flat areas deposition has been by turbidity currents. Cores should be taken to prove whether this hypothesis is correct. Flat areas are very suitable for deep-sea dredging by the KULLENBERG (1952) technique. Surveys should also be made of seamounts associated with deep-sea trenches.

The nature of deep-water in trenches presents many fascinating problems, especially in close proximity to the floor. There are many interesting problems associated with the animal life at these great depths, as well as the bacteria content of the sedi-

ments. Work in this field has recently been carried out by the Danish Galathea Expedition (BRUUN, 1951). Systematic plankton hauls throughout the year in the upper layer are required, so that the organisms found in the sediment can be compared with the living assemblage of diatoms, radiolaria, planktonic foraminifera and coccoliths. Finally benthonic foraminifera, in samples from various depths, should be investigated, as work on these lines may give evidence of turbidity currents.

Table 1. *Localities at which* Ethmodiscus *ooze has been found*

	Station No.	*Date*	*Position*	*Depth*	*Species*
H.M.S. *Challenger* 1872-76	225	23.3.1875	11° 24.0′ N 143° 16.0′ E	4475 fm. (8186 m)	*Ethmodiscus rex*
	265 —	25.8.1875	12° 42.0′ N 152° 1.0′ W	2900 fm. (5305 m)	*Ethmodiscus rex* *Ethmodiscus gazellæ*
	229	1.4.1875	22° 01.0′ N 140° 27.0′ E	2500 fm. (4545 m)	*Ethmodiscus rex*
H.M.S. *Challenger* 1950-51	—	29.10.1951	11° 20.0′ N 142° 19.0′ E	5744 fm. (10505 m)	*Ethmodiscus rex*
H.I.J.M.S. *Mansyu*	234	25. 5.1926	19° 08.5′ N 153° 06.5′ E	3124 fm. (5714 m)	spec. indet.
H.I.J.M.S. *Kosyu*	10	27.4.1933	16° 12.4′ N 136° 32.6′ E	2827 fm. (5171 m)	spec. indet.
	73	13.7.1933	9° 21.0′ N 146° 50.0′ E	2548 fm. (4660 m)	spec. indet.
	32a	29.6.1933	8° 04.0′ N 142° 15.0′ E	2537 fm. (4822 m)	spec. indet.
H.I.J.M.S. *Yodo*	60	9.3.1928	12° 50.1′ N 147° 29.6′ E	2549 fm. (4662 m)	spec. indet.
U.S. Steamer *Nero*	746	14.7.1899	14° 24.0′ N 135° 31.00′ E	2788 fm. (5100 m)	*Ethmodiscus rex*
S.M.S. *Gazelle* 1874-76	125	15.11.1875	30° 53.00′ S 177° 6.00′ E	2270 fm. (4151 m)	*Ethmodiscus gazellæ*
	96	12.3.1876	9° 57′ S 121° 52′ E	1630 fm. (2981 m)	*Ethmodiscus gazellæ*
U.S. F.C.S. *Albatross* 1888-1904	—	—	Neighbourhood of Philippine Islands *	—	*Ethmodiscus gazellæ*
	4674	22.11.1904	12° 14.4′ S 78° 43.4′ W	2338 fm. (4276 m)	spec. indet.
Albatross 1947-48	—	—	5° 45.0′ N 21° 43′ E	1956 fm. (3577 m)	*Ethmodiscus rex*

* MANN (1907) gives no station number and no date.

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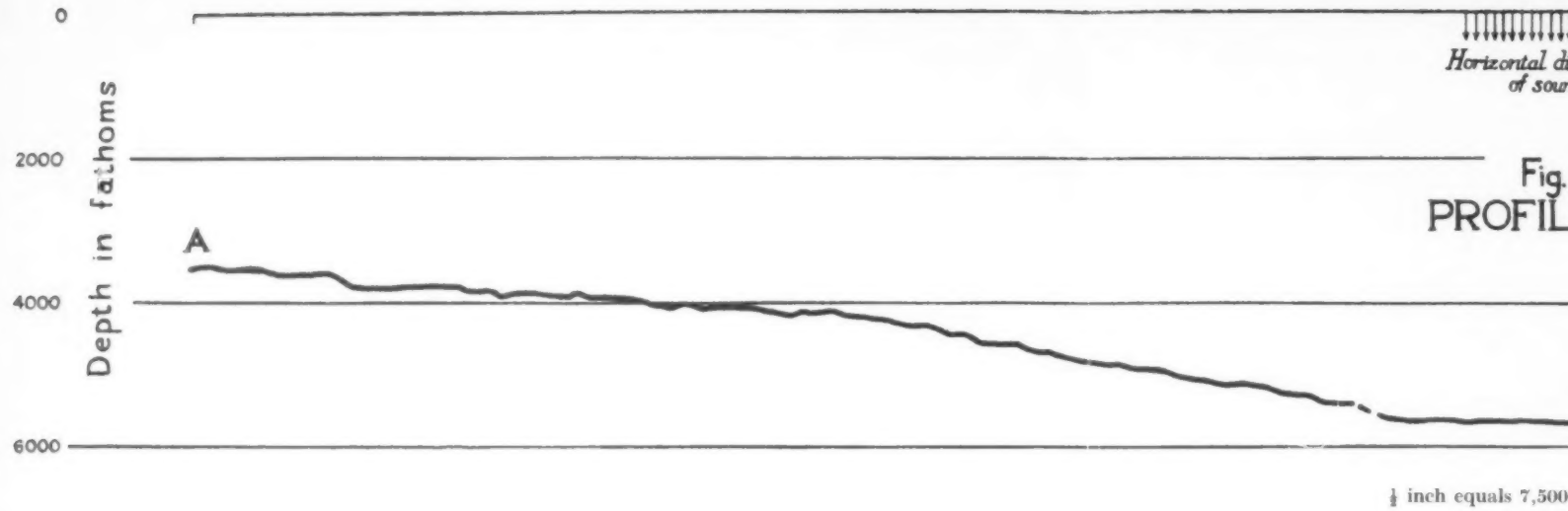


Fig.
PROFIL

½ inch equals 7,500

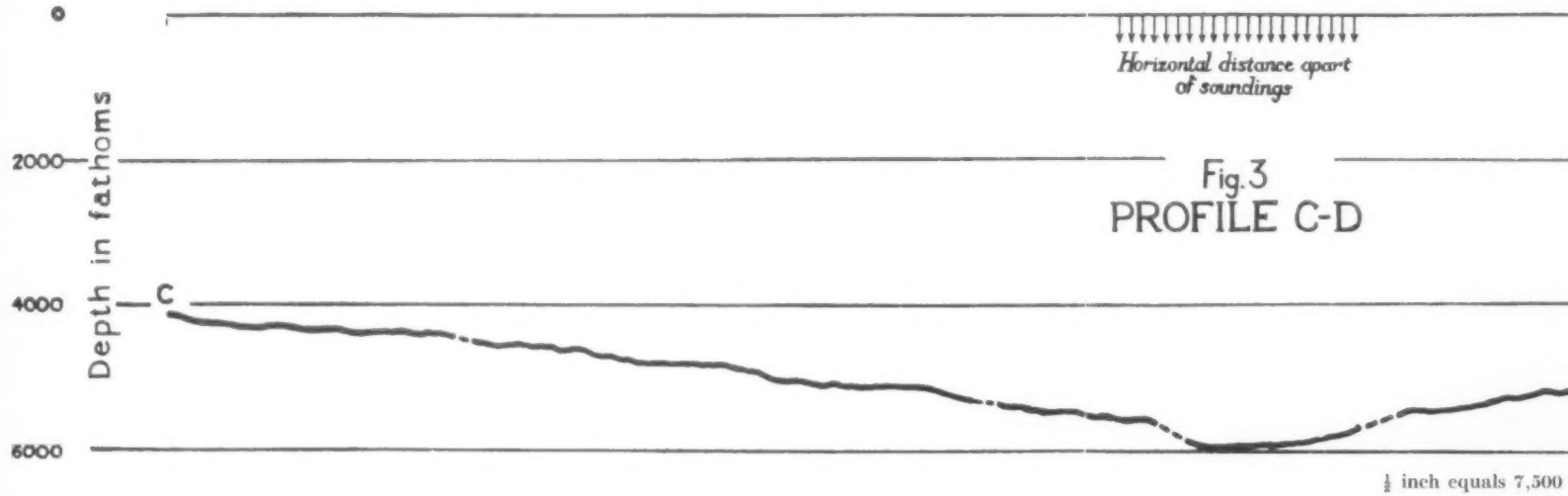
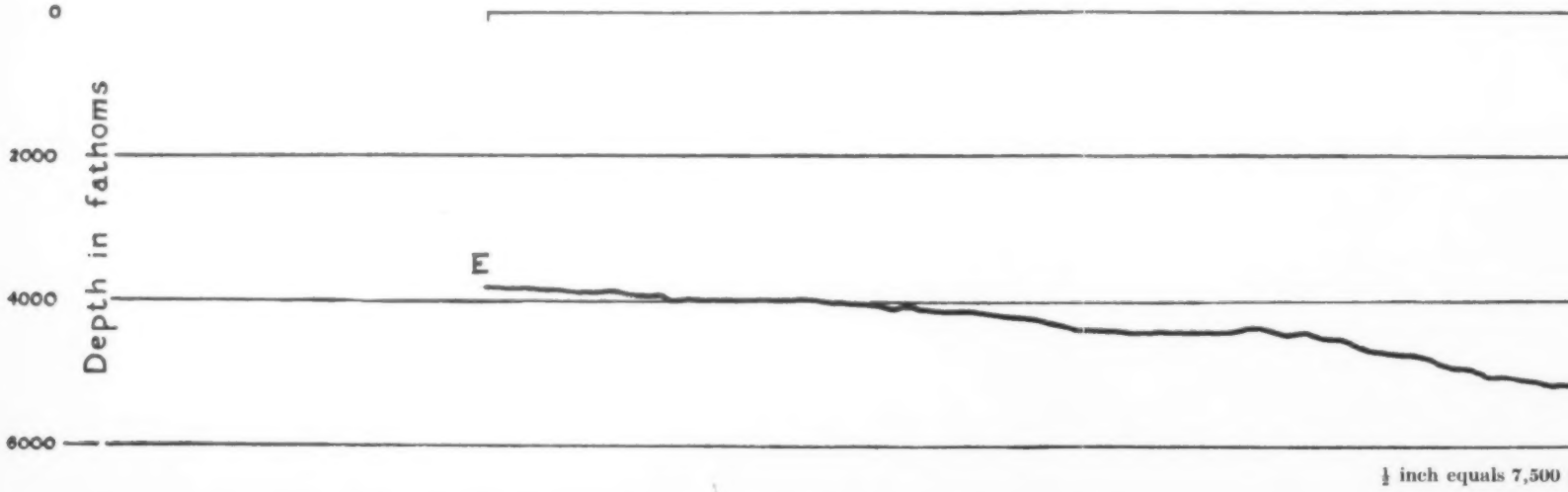


Fig.3
PROFILE C-D

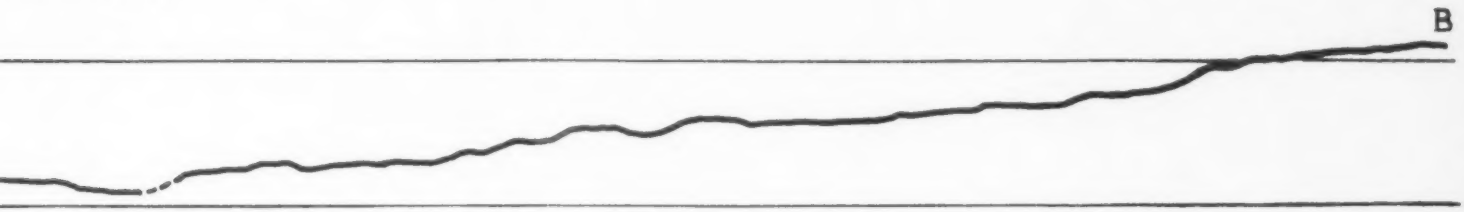
½ inch equals 7,500



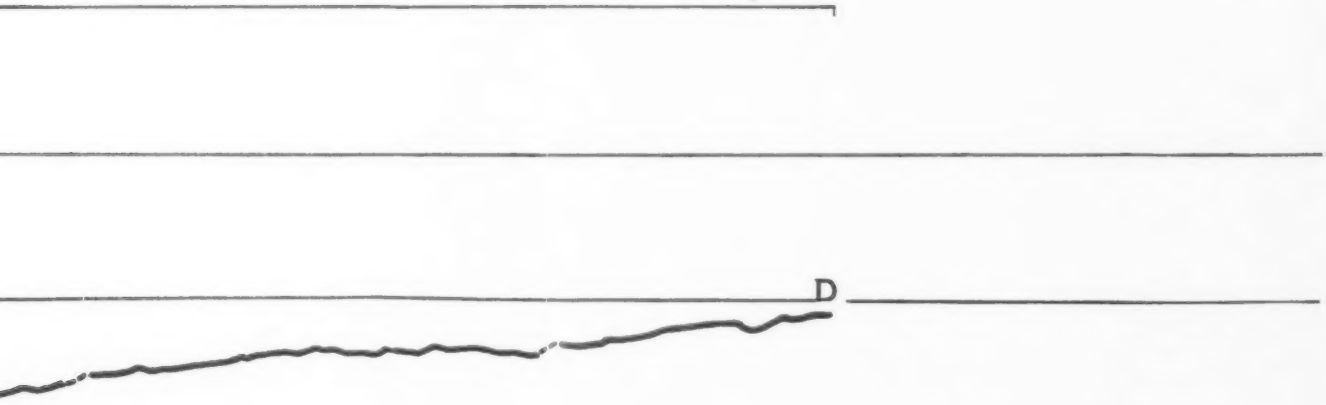
½ inch equals 7,500

al distance apart
f soundings

Fig. 2
FILE A-B



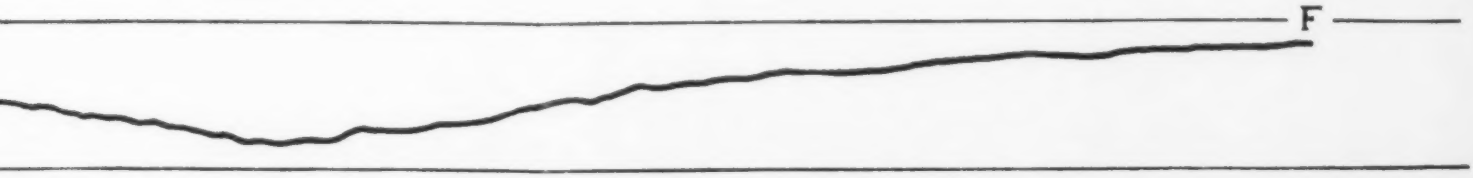
7,500 feet.



7,500 feet.

Horizontal distance apart
of soundings

Fig. 4
PROFILE E-F



7,500 feet.

2 3

Deep-Sea Research, 1953, Vol. 1, pp. 60 to 63. Pergamon Press Ltd., London.

Further notes on the greatest oceanic sounding and the topography of the Marianas Trench

By Dr. T. F. Gaskell, J. C. Swallow and Cdr. G. S. Ritchie, R.N.

Summary—A bathymetrical chart and profiles in the neighbourhood of the deepest oceanic sounding are given. The area is one where good relative position fixing is possible, because of the Marianas Loran chain. The methods used in checking the deep-sea soundings are described. A bottom sample from a depth of 5,744 fathoms was obtained by means of a Baillie Rod.

INTRODUCTION

The details of the circumstances in which a new deep ocean sounding was obtained by H.M.S. *Challenger* in the Marianas Trench has been given by Carruthers and Lawford (1952). Now that *Challenger* has returned to the United Kingdom further details of the sounding and profiles, together with a report on the examination of the sea-bed sample, now in the possession of the British Museum (Natural History), are available (Wiseman and Hendey 1953).

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CONFIGURATION OF MARIANAS TRENCH

Fig. 1 shows the contours drawn in the vicinity of 11° 20′ N, 142° 16′ E. The depths greater than 4,000 fathoms are based on the following :—

(a) Profile A-B where soundings were read off every 800 feet along the ship's track.

(b) Profile C-D where soundings were read off every 1,000 feet along the ship's track.

(c) Profile E-F where soundings were read off every 4,000 feet along the ship's track.

(d) Profile G-H where soundings were read off every 1,500 feet along the ship's track.

(e) 4 short sounding traverses across the trench (J, K, L and M) when continuous sounding was carried out, care being taken to record the deepest sounding obtained. The ship was fixed by Loran, and the echo-sounding speed was checked at both ends of these short traverses.

(f) Two wire soundings giving readings of 5,954 and 5,868 fathoms (uncorrected for slope) were taken with the taut wire measuring machine.

(g) Two wire soundings of 5,922 and 5,744 fathoms were taken with the Lucas sounding machine.

(h) Eight reflection shots were taken with the seismic apparatus.

A number of other soundings were taken in the vicinity, the positions of which are shown by dots on Fig. 1.

PROFILES

Figs. 2, 3 and 4 show detailed profiles A-B, C-D and E-F. The pecked portions of A-B and C-D are parts of the profile where the echo could have come from a neighbouring part of the sea-bed (found by describing arcs, of radius the sounding-depth, about the position of the ship at the time of the sounding). The depth may be slightly under-estimated in these parts but there does not appear to be any gross error due to side echoes.

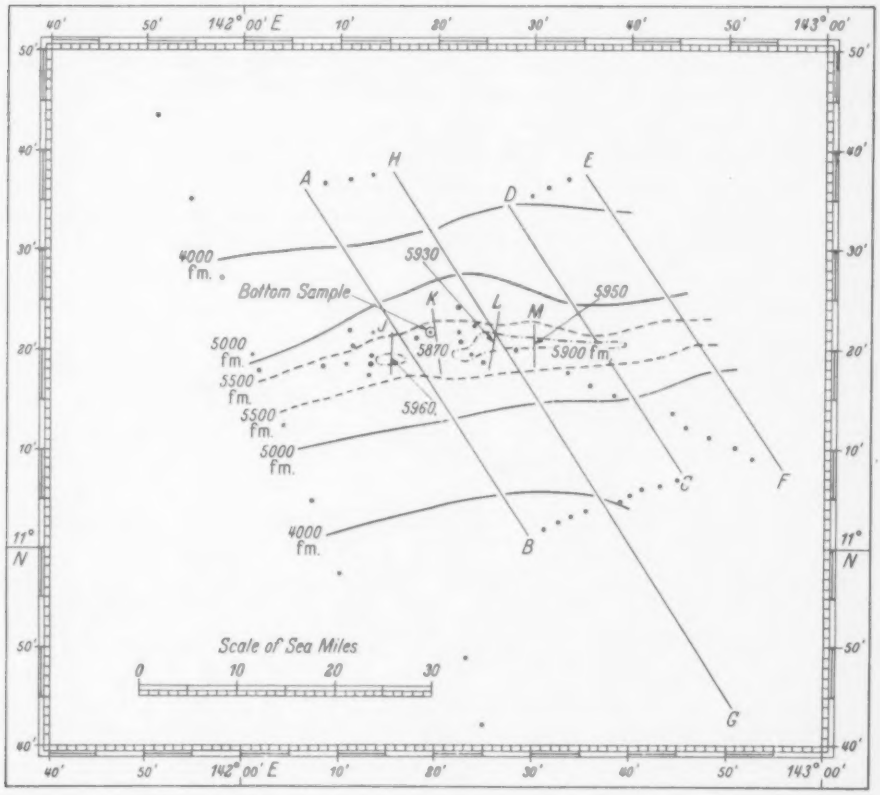

Fig. 1.

The echo was sometimes lost for a few consecutive transmissions, but was always loud and clear at the deepest part of the trench. The weak echoes may come from steep slopes, and soundings taken at one minute intervals do sometimes show sudden changes of 50-70 fathoms after a flat bottom stretch of several minutes duration. The steepest slopes are of the order of 1 in 2 at least ; several slopes at 1 in 6 extend for 1-2 miles ; stretches of flat within 10 fathoms exist from 1-2 miles ; the slope from 4,000 fathoms to the bottom of the trench is about 1 in 7 ; and the approach to the trench from 3,000 fathoms to 4,000 fathoms is about 1 in 18.

LOCATION OF SOUNDINGS

It was fortunate that the area about 11° N. 142° E. is an area where reasonable Loran cover is available on the Marianas Loran Chain, and reasonably good relative fixing was available. The accuracy of these Loran fixes is probably about ± 3 miles in the N.W./S.E. direction and ± 0·3 miles in the N.E./S.W. direction.

Star sights were obtained under good conditions and gave positions about 2 miles to the north-west of those given by Loran.

The positions of all soundings shown on Fig. 1 are those obtained by Loran.

CHECKS ON THE DEEP SOUNDINGS

Although the echo sounding results are the most useful for obtaining a detailed picture of the trench, three independent methods used for taking soundings in the trench give a good check on the absolute values of the soundings :—

(a) *Explosion—hydrophone system.* The depths obtained by this method depend on the reflection of audio-frequency sound from the sea-bed, and hence on the uncertain knowledge of the velocity of sound in sea water, as do those from a 10 k/c. echo sounder. However, photographic recording allows the travel time to be read at leisure, and the timing system (provided by a tuning-fork controlled synchronous motor) was calibrated against time signals, so that this system is independent of the echo-sounder. Furthermore, the hydrophone records the form of the train of echoes from the sea-bed and is able to distinguish a small, shortest-time path signal, from any large return of energy sent back by a good reflecting surface displaced sideways from the ship. It was necessary to stop the ship to employ this technique, but it was of great use during the first visit to the trench when the echo-sounder could not obtain a reading. The greatest depth recorded by this method, using a $1\frac{3}{4}$ lb. T.N.T. charge, was 5,882 fathoms.

(b) *Echo Sounding Machine.* The method of reading the machine has been fully described by CARRUTHERS and LAWFORD (1952) and it is only necessary to add that the corrections applied to the soundings for the velocity of sound in sea-water were obtained by extending the tables given by MATTHEWS (1939). Soundings shown along the centre of the trench in Fig. 1 are as read off the echo-sounder scale with Matthews. A correction of one scale division of the recorder, 20 fathoms, should be subtracted from the deepest sounding of 5,960 fathoms to allow for a possible error in reading the scale.

(c) *Wire Soundings.* These have also been discussed by CARRUTHERS and LAWFORD (1952) but owing to an ambiguity in the written report forwarded from the ship it was assumed by the writers that the length of the wire was measured on re-winding after the bottom had been reached. In fact the 140 lb. weight was lowered on 0·029″ diameter wire and the wire paid out was measured by running over a wheel of known diameter. A gradually increasing brake pressure was maintained on the wire drum to balance the weight of the wire so that the drum stopped when the pull of the 140 lb. weight ceased as the bottom was reached.

With the arrangement of sounding gear used corrections to the wire sounding for slip and stretch of the wire over the measuring wheel are small and act in opposite

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directions. Any slip will give an apparent reading less than the real depth, but it is difficult to estimate, and the stretch, which amounts to about 5 fathoms will cause an apparent increase in depth. The total effect of these two corrections on the final sounding is probably negligible. If therefore we apply the minus 55 fathoms correction for slope proposed by CARRUTHERS and LAWFORD (1952), then the deepest wire sounding becomes 5,899 fathoms.

BOTTOM SAMPLE

After several attempts a bottom sample was obtained from depth of 5,744 fathoms (see Fig. 1) in the trench. The Baillie rod sampler with sinkers was used to obtain the sample. The 5,000 fathom Lucas sounding machine, with an extra 2,000 fathoms of sounding wire spliced in, was used to lower and recover the Baillie rod. The outer 100 fathoms of the wire attached to the Baillie rod was laid up inside a $1\frac{1}{2}''$ rope tail to avoid kinking of the wire and subsequent parting, which was the cause of the unsuccessful attempts. The weights took $1\frac{1}{2}$ hours to reach the sea-bed and 4 hours was taken to recover the Baillie rod.

CONCLUSION

The " point readings " taken by wire and by hydrophone are not as great as the maximum value 5,940 fathoms obtained from the echo sounder profiles across the bottom of the trench, but this is to be expected because the trench is narrow. All three methods give depths greater than 5,880 fathoms. It is therefore probable that depths of 5,940 fathoms exist, and that there is a considerable area greater in depth than 5,900 fathoms.

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JOINT COMMISSION ON OCEANOGRAPHY

of the International Council of Scientific Unions.

A symposium entitled *The Deep-sea Floor and the History of the Earth* was held in the Jane Herdman Geology Laboratories of the University of Liverpool on 1 and 2 September.

Papers were read embracing results of research on deep-sea sedimentation from geological, geophysical and biological standpoints with evidence for possible changes in ocean-volume and climate of the past. Morphology of the deep-sea floor, interpretation of continuous echo-sounding records and the preparation of bathymetric charts were also discussed. The focus of the whole conference was upon the contribution of the various lines of work to the elucidation of the earth's history.

Among the speakers were : F. BERNARD, Algeria ; E. C. BULLARD, Teddington ; C. W. CORRENS, Goettingen ; L. FAGE, Paris ; M. N. HILL, Cambridge ; P. E. KENT, London ; F. KOCZY, Gothenburg ; Ph. H. KUENEN, Groningen ; J. D. NARES, International Hydrographic Bureau ; H. PETTERSSON, Gothenburgh ; R. REVELLE, La Jolla, Cal. ; J. D. H. WISEMAN, London ; C. ZOBELL, U.S.A.

The papers and discussions of the Symposium will be published in this journal.

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Resumé of paper delivered at Symposium of the Joint Commission on Oceanography at Liverpool 1-2 September 1953

Heat-Flow through the floor of the ocean

E. C. BULLARD

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IT has recently become possible to measure the amount of heat flowing through the floor of the ocean. The measurements involve the determination of the rate of increase of temperature downward into the sediments and of the conductivity of the sediments. The conductivity is measured in the laboratory, on samples collected from the bottom. The temperature gradient is determined by forcing a probe carrying recording thermometers into the bottom. The probe used in the Atlantic in 1952 was 15 ft. long and 1 in. in diameter. It contained two thermo-junctions, one near the tip and one near the top. These were connected to a galvanometer in a pressure-tight case at the top of the probe. The deflection of the galvanometer was recorded by a photographic film on a rotating drum. When the probe enters the bottom it is warmed by friction, and time must be allowed for this heat to dissipate itself by conduction. In about half and hour the disturbance has fallen to 5 or 10% of its initial value and the remainder can then be removed by extrapolation. A thorough investigation has been made of the instrumental errors and there is little doubt that the conductivities and temperatures are measured with an error of not more than 10 per cent.

Measurements have been made in the Central Pacific and in the north-western Atlantic. The results are unexpected. The heat flow from six stations in the Pacific was found by REVELLE and MAXWELL to average $1{\cdot}2 \times 10^{-6}$ cal/cm^2 sec, and from six stations in the Atlantic to be about $1{\cdot}0 \times 10^{-6}$ cal/cm^2 sec. These values are quite comparable with the average value found on the continents, which is $1{\cdot}2 \times 10^{-6}$ cal/cm^2 sec. It is not certain that this result is to be taken at its face value. It is possible that what is measured at sea is not the equilibrium heat flow but the after-effects of a climatic change. Whilst this possibility must be borne in mind, it does not seem a very likely explanation of the observations, as it requires a change of several degrees in the bottom temperature during the last few thousand years. The temperature of the bottom water is controlled by the temperature of the cold water which sinks in the Arctic and Antarctic, and travels towards the Equator. The temperature of this water cannot have changed greatly so long as there has been ice in the polar seas.

If the quantity measured is a genuine estimate of the equilibrium heat flow from the rocks beneath the ocean, it raises a most interesting problem. The whole heat-flow on the continents can be provided by the radioactivity of 20 km of typical continental basement rocks (granites, granite gneisses, etc.). It is usually supposed that the radioactivity decreases rapidly downwards and that, in fact, about $0{\cdot}8 \times 10^{-6}$ cal/cm^2 sec comes from the crust, which is about 35 km thick, and the remaining $0{\cdot}4 \times 10^{-6}$ cal/cm^2 sec from greater depths. If the crustal rocks were completely

absent from the oceans and were replaced by rocks similar to those beneath the continental Mohorovičić discontinuity, the heat flow would be about $0{\cdot}4 \times 10^{-6}$ cal/cm^2 sec. This is only raised by about $0{\cdot}06 \times 10^{-6}$ if allowance is made for 4 km of basalt above the oceanic Mohorovičić discontinuity.

There are very few reliable measurements of the radioactivity of oceanic rocks, but it seems most unlikely that their radioactivity can be high enough to account for the observed heat-flow without assuming that the heat is derived from a thickness of rock measured in hundreds of kilometres. If this heat were conducted to the surface it would involve temperatures reaching the melting point at a depth of a few hundred kilometres. This cannot be correct, as *S* waves from earthquakes can be propagated at all depths down to the surface of the core at 2,900 km. If melting is to be avoided, the radioactivity must be confined to about the outer 150 km, the amount of radioactivity needed to give the observed heat flow is then 10 or 20 times what is found in the few samples that have been examined.

A possible escape from this difficult is to suppose that the heat is brought from a great depth by convection currents in the mantle. This would require a much smaller temperature gradient than would transfer by conduction. This mechanism of heat transfer presents all the difficulties that have been urged against the convection theories of orogenesis due to VENING-MEINESZ, HESS and others. It differs from them in that the rising currents would lie beneath the oceans and the sinking ones beneath the continents and not *vice versa*.

It is evident that the results of the few measurements that have been made have raised questions of the greatest interest. It would be rash to draw far-reaching conclusions from a dozen measurements and the main need is for more observations. It is desirable to modify the equipment to give a greater penetration of the ocean bottom and to enable measurements to be made at several depths so that the linearity of the temperature-depth relation can be examined. The present results show considerable variations from place to place, which are believed to be genuine. It would be of great interest to obtain closely spaced lines of observations and to correlate the results with seismic observations.

National Physical Laboratory, Teddington

DISCUSSION

Mr. Gaskell: Have any heat flow measurements been made where there is a typical deep ocean structure; that is, where a 6·3-6·7 Km./sec. layer is covered by about 0·5 Km. of sediment and where no interposed layer of 4-5 Km./sec. material exists?

E. C. Bullard: So far as is known both the areas in which REVELLE and MAXWELL made their measurements in the Pacific, and those in which the measurements were made in the Atlantic are typical deep ocean basins.

Deep-Sea Research, 1954, Vol. 1, pp. 67 to 71. Pergamon Press Ltd., London.

Paper read at Symposium of the Joint Commission on Oceanography at Liverpool, 1-2 September 1953

The Geological History of the Oceans

G. M. LEES

(*Received 23rd November* 1953)

Abstract—The geophysical conception of permanence of oceans conflicts with observed geology. The compression zones of continents strike boldly into the oceans in many cases and the complex pattern resulting from repeated phases of compression makes it unlikely that oceanic floors and continents can be fundamentally different. There is abundant evidence of mobility within and along the margins of the oceans. Downwarps of continental margins since early Cretaceous of 35,000 and perhaps 50,000 ft are known. The layered structure of continents suggested by seismic results is quite unacceptable geologically and the Mohorovičič discontinuity must have some other explanation.

THE results of oceanic research during recent years has added greatly to our factual knowledge of many aspects of the nature of ocean bottoms and of the factors governing sedimentation in oceanic depths, but a satisfactory explanation of many fundamental problems seems still far off. We are still suffering from the handicap of ideas developed in the early formative years of geological and geophysical thought and it is important that we should critically review the basis of these ideas in the light of greater experience. I have attempted to do this in my 1953 Presidential Address to the Geological Society of London (now in the press), and this note is largely a summary of that address.

The conception of permanent oceans, which I challenge on geological deduction, has developed through the years through a belief that there is a fundamental difference between the nature and composition of ocean floors and of the adjacent continents. It was thought that 'the oceans' constitute a unit problem because they are a consequence of a transition from a molten earth to an earth with a molten interior and a solid crust, the lighter minerals floating to the surface and forming patches of scum which became the continents, while the swept areas of molten basic lava formed the low level sites of the oceans which were filled as soon as sufficient water condensed.

Geology does not give any support for these assumptions. The earth's crust was already old at the time of the oldest rocks now revealed at the surface, estimated by radioactive disintegration at the about 2,000 million years. The cycles of compression, mountain formation and erosion by atmospheric agencies were already then an established regime. Igneous activity, both intrusive and extrusive, was manifest from the earliest revealed time onwards and was not more intensive at the beginning of the record than subsequently. Pre-Cambrian lava flows were on a comparable scale with the Deccan Trap of India or with the late Tertiary outpourings of East Greenland which attain a thickness of about 15,000 feet, for example.

The continents as we now see them are compounded of highly compressed rocks, the strata being thrown into fold and thrust mountain belts, in the case of the youngest mobile belts, or into a complex pattern of metamorphic zones with many

igneous intrusions, in the case of older belts where subsequent erosion has revealed deeper structure. There is no place where the original undisturbed crust of the earth is exposed. The zones of compression are narrow strips in relation to their length; the youngest mountain system, the Alpine-Himalayan-Andean, is world-encircling, and so by inference the earlier zones may have similarly been so. Three main periods of compression or orogenesis are known since the Cambrian, and at least three, perhaps many more, in pre-Cambrian time. These compression zones form a complex pattern through the continents, crossing and recrossing one another without any discernible system. Some areas have been involved in several compression phases, others seem to have developed a degree of rigidity in pre-Palaezoic time and to have resisted subsequent pressure, the Canadian Shield for example. The margins of the present continents do not show any structural design at all suggestive that they have always been margins. It is the exception rather than the rule for a coast to be determined in its alignment by the grain of a fold or compression system. The west coasts of North and South America, are, of course, the consequence of the Rockies and Andean mountain system, but the Central American coast is not so. There is moreover sound evidence for a reconstruction of the Rockies-Andean geosyncline, showing that it is in reality an intra-continental and not a marginal feature, and a land area of unknown extent must have existed in the Pacific to provide detrital material for the clastic rocks in the western part of the geosyncline. Also where the South American continent tapers to its minimum width in Tierra del Fuego and in its continuation in the Falkland Islands it is beyond reason to presume that the continental margins were always as they are now.

In other continental areas there are many instances of compression zones, not necessarily now physical mountains, striking at strong angles to the present continental coast. The sector of the Anti-Atlas mountains south of Agadir is an interesting example. Here there is an intense compression system of pre-Cambrian age, the grain of which strikes resolutely at right angles to the present coast and so crosses the continental margin into the unknowns of the Atlantic. The mountains formed by this remote orogenesis were eroded to their stumps and subsequently a thick cover of sediments of late pre-Cambrian and early Palaezoic buried their bones, until, in the late Palaezoic, the Hercynian orogenesis rejuvenated the mobility of the zone, though in an entirely different direction and parallel to the present coast. Mesozoic sedimentation followed and the final event was the formation of the High Atlas mountains in the late Tertiary; these strike boldly into the Atlantic at Agadir thus being parallel to the pre-Cambrian strike and at right angles to the intervening Hercynian direction of movement. Similar cases can be quoted along many continental margins of compression zones striking boldly into the oceans, and the simple inference is, in my opinion, inescapable that the oceans must conceal a comparable complex of compression zones continuous with those of the continents.

The oceans should not be considered as a unit problem; each one has had its separate past history as complex as the many segments of the continents. It was at one time thought that the great oceans are immense flat-bottomed expanses, immobile and unchanging. Recent research and wider knowledge have revealed that the ocean floors have, in fact, a very rugged topography and a considerable mobility. Vertical movements of the ocean floors on a large scale have taken place during the Tertiary and since early Cretaceous down-warpings of continental margins

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have been so vast that it is no longer possible to speculate on the size or even the position of pre-Cretaceous oceans.

As evidence of young movements within the oceans the existence and position of sea-mounts and atolls may be cited. Oceanographic exploration in both the Pacific and Indian Oceans has revealed a large number of surprising features known as sea-mounts or guyouts. These are flat-topped peaks or long ridges which rise abruptly from the ocean bottom to depths of 1,000 to 5,000 feet below the present sea level. The flatness of the tops suggests that they must have been bevelled by erosion at sea level and have subsequently been depressed to their present depth. Many are nearly circular in outline and are suggestive of volcanic peaks, but others, as in the Gulf of Alaska, have long hog-back shapes more suggestive of fold mountains. A boring in 1952 on Eniwetok Atoll, Marshall Islands, which may be considered as a sea-mount which has managed to remain at the surface by sedimentation keeping pace with subsidence, encountered basalt at 4,208 feet below sea level, under shallow water limestones of Recent, Miocene, and Eocene ages. This is an extremely interesting result showing that subsidence was continuous for a very long time, but of course nothing is learned about the composition of the ocean floor other than that during or before the Eocene there was a volcanic episode. In describing the results (H. S. LADD *et al. Bull. A.A.P.G.*, Vol. 37 1953) the volcanic rock is referred to as ' basement rock ' but this term is quite misleading as only 14 feet of basalt was penetrated and there is no evidence on its total thickness or on what may underlie it.

The margins of the continents also provide abundant testimony of large-scale down-warping during the Cretaceous, Tertiary and even Recent times on a scale comparable with vertical movements within the continents themselves. As examples I have described in my Geological Society Address the conditions in the Gulf of Alaska, along the sea-board of North Carolina and along the coastal zone of Nigeria, French Equatorial Africa and Angola. These down-warps since early Cretaceous amount to at least 35,000 feet in places and might even exceed 50,000 feet. It might of course, be argued that these great vertical movements affect only a narrow zone adjacent to the continents, but even so all the circumstances demand a breadth of this mobile zone of several hundred miles in some cases; and if the margin between ' continent ' and ' ocean ' lies at an unknown distance within the deep ocean itself any attempt to presume and to define a boundary between the two looses all sense of reality.

Thus far I have only presented an outline of the geological case. In my opinion there is no geological evidence for an assumption that the oceans have been permanent, and there is abundant palaeogeographic evidence indicating extensive continental areas in parts of the present oceans. It is difficult to envisage a mechanism which could have repeatedly compressed the continents into such a complex structure if there were a fundamental difference in both composition and rigidity between oceans and continents.

The other half of the problem turns on geophysical data which is commonly thought to support an opposite interpretation. Seismic investigations in continental areas show a gradual increase in transmission velocity with depth until at a level about 35 km. from the surface there is an abrupt change from about 6·5 km./sec. to about 8·2 km./sec. A geophysical conception of a layered structure of the rocky

crust has been built around these observations. A granitic layer of about 12 km. in thickness is supposed to overlie an intermediate layer of basaltic composition and of about 24 km. in thickness, and this in turn rests on the 8·2 km./sec. medium (the Mohorovičić discontinuity) which is interpreted as rock having the composition of dunite or peridotite. The hypothesis of isostasy presumes that this low layer is viscous and permits of slow flow and that the major gravity anomalies observed at the surface are due to crustal blocks floating on the mobile substratum and depressing it differentially.

This conception of a layered arrangement of the earth's outer crust is in strong opposition to observed geological structure. The steep fold and thrust compression zones have produced a pattern of great complexity, but in the lowest levels seen, steepness rather than horizontal layering is the dominant motif. The structures both of young mountain zones and of pre-Cambrian shields must have a vertical extension at least two or three times that of the Mohorovičić discontinuity and therefore some more acceptable explanation of the geophysical facts must be sought. I have suggested that physical changes in density and rigidity due to the pressure and temperature at this depth may be the answer, and the high-pressure researches of P. W. BRIDGMAN support such a possibility.

Under the oceans the 8·2 km./sec. velocity layer is found at much shallower depth, 6 km. or so, and hence the belief that there is no rocky crust under the ocean floors comparable with the continental "granitic" layer. This result cannot be explained as the consequence of high pressure as the depth is not sufficient, and the possibilities of other explanations must be explored. I have described briefly some of the geological reasons for a reluctance to believe that there can be a fundamental difference between continents and the basement of ocean floors. Yet there must be some reason for these great downwarps of the earth's crust now occupied by the oceans. Perhaps the wide spread vulcanicity characteristic of some oceanic areas is an essential accompaniment to the development of these deep depressions; lava outpourings on the ocean floors, 20,000 or even 50,000 feet or more in thickness is quite a possibility, particularly in view of known occurrence of thick basalt flows along continental margins such as the Deccan Trap and the East Greenland lavas. Such thick lava accumulation perhaps reinforced by many sills and dykes and ejected on the ocean floor beneath a load of 5 km. or so of water might have the physical characteristics which would satisfy seismic and gravity requirements; at least this is one possibility.

It is clear from the foregoing that oceanographic research must be conducted with a full awareness of all aspects of the problems. The simple hypothesis of the permanence of oceans has been accepted too uncritically and geophysical deductions have unduly influenced geological opinion, largely because they have been credited with an authority which has seemed unchallengeable. Further research should be carried out in critical areas where the correctness or otherwise of conflicting hypotheses can be controlled; geologists must co-operate fully with geophysicists and neither must under-rate the value of the evidence of the other, and the final answer must be acceptable to both.

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Discussion

C. M. G. Bolton

In his paper Dr. Lees stressed the intense folding of the continental areas, but he maintained that there was no fundamental difference between the continental and oceanic rocks, a point which seemed to be in direct contradiction to the general tenor of the two preceding papers on this question. These papers appeared to show that the rocks of the ocean floors (with the possible exception of the mid-Atlantic ridge) were :

(a) predominately of " basaltic " composition ;
(b) apparently mainly volcanic, as shown by the " sea mounds " on a relatively flat floor ;
(c) not obviously deformed by typical close-packed folds characteristic of consolidated stratified deposits.

There was also evidence of the predominance of rifting, and it seems likely that the mounds on the ocean floor will be found to be aligned on fractures as is the case in Iceland where somewhat similar conditions of basaltic volcanism hold.

In the opinion of the writer the intense folding of the continental rocks and the manner of deformation by rifting of the oceanic rocks can be attributed to fundamental differences in both the composition and the physical properties of the two main rock-types comprising these two areas. The continental (sialic) rocks are composed (at depth) mainly of granite or rocks of granitic composition, in which quartz is present as an essential constitutent. The basaltic rocks, on the other hand, are deficient in silica and so do not contain free silica as quartz. The former, which geological evidence shows are highly compressed, appear to have re-acted to compressional stresses by accommodation first by elastic strain and then by plastic deformation largely by virtue of the apparent " flow " by re-crystalization of their main mineral constituent, quartz, under certain (metasomatic) conditions occurring at depth. The basaltic rocks have re-acted more readily to tensional stress by fracture and subsequently by the intrusion of basaltic magma to form the dykes and volcanic rocks typical of the oceanic areas. While midway processes are also possible, these two actions (in conjunction with the many other geological processes affecting the earth's surface rocks), in the opinion of the writer have been largely responsible for segregating the rock masses of the earth's surface into predominantly " oceanic " and " continental " rocks.

Deep-Sea Research, 1954, Vol. 1, pp. 72 to 77. Pergamon Press Ltd., London.

Paper read at the Symposium of the Joint Commission on Oceanography, Liverpool, September 1953

Synopsis of future plans for the preparation of sheets of the General Bathymetric Chart of the Oceans

Vice-Admiral J. D. NARES, D.S.O.

THE question of the production of the Bathymetric Chart of the Oceans was one of the subjects discussed at Monaco in September 1952 at the meeting of the International Joint Commission on Oceanography. The first meeting was held in the International Hydrographic Bureau where full details regarding the preparation and publication of the 3rd Edition were demonstrated to the Members.

After lengthy discussion the following recommendations of the International Joint Commission on Oceanography were made:

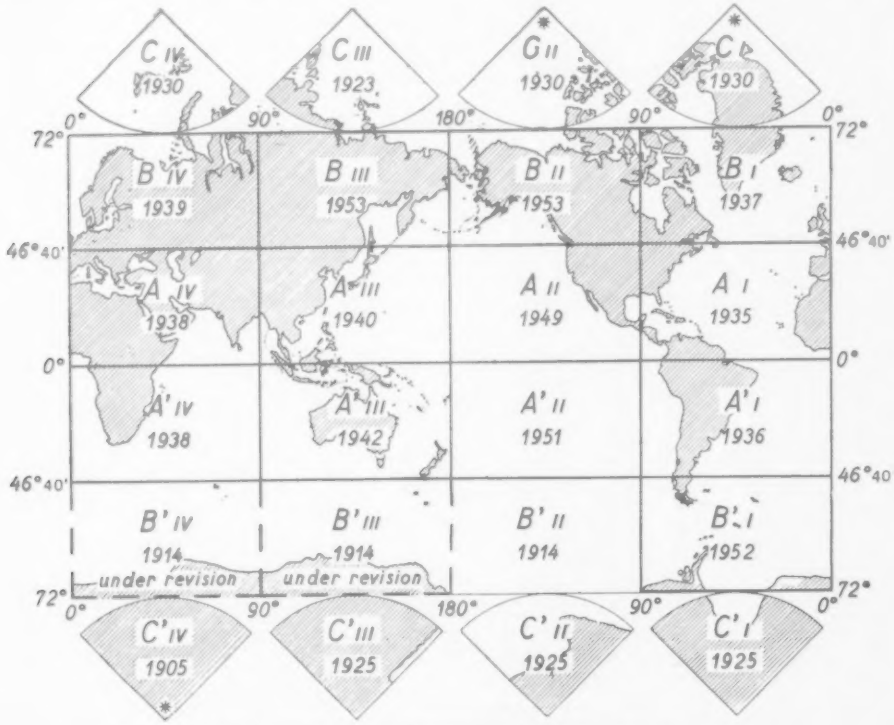

Fig. 1. Key to the sheets of the General Bathymetric Chart of the Oceans.

1. PUBLICATION OF BATHYMETRIC CHARTS

The International Hydrographic Bureau with its present budget could produce *one* sheet of the Bathymetric chart of the Oceans per year, corresponding to a cycle of about 20 years per edition.

To bring this down to the 5-year cycle, which is considered essential if the charts are to be of real value to scientists and navigators, *Four sheets* a year are necessary. This would require an additional 7,500 dollars per annum approximately to meet publication costs.

The International Council of Scientific Unions is asked to make a beginning with an annual grant of 2,500 dollars to the International Joint Commission on Oceanography, at least until the date of the next International Hydrographic Conference, which would cover the cost during that period of the publication of *one more* sheet per year.

2. AVAILABILITY OF BATHYMETRICAL DATA

The International Joint Commission on Oceanography request the International Hydrographic Bureau to transmit to its States Members the following recommendations:

(*a*) That every effort be made to increase the scientific and navigational value of the General Bathymetric Chart of the Oceans, as well as to speed up their rate of production. It is considered that a new edition of these charts should be issued at least once every five years.

(*b*) That, in view of the great importance of accurate Bathymetrical Charts to navigation and to deep-sea oceanography, deep-sea soundings should be made freely available by all countries.

(*c*) That copies of echo-traces should be made generally available for detailed morphological investigation.

3. AVAILABILITY OF THE GENERAL BATHYMETRIC CHART PLOTTING SHEETS

The International Joint Commission on Oceanography strongly recommends to the International Hydrographic Bureau that copies of the Bureau's plotting sheets with complete up-to-date soundings should be made available for expert use.

With reference to Recommendations 1 and 2, the Commission were informed that, provided the necessary funds for the printing of a second sheet were made available, the Bureau could prepare two sheets annually during the next five years, without augmenting our present staff, this being in accordance with the Resolution of the VIth International Hydrographic Conference 1952, " that the International Hydrographic Bureau should continue the work of publishing the General Bathymetric Chart of the Oceans under preceding conditions. The acceleration of this work might be contemplated if International Organizations interested in bathymetry would supply the International Hydrographic Bureau with the appropriate financial resources."

In March 1953 the International Hydrographic Bureau had accumulated sufficient funds to pay for the three new sheets B'1, BII and BIII which it was anticipated would be issued during 1953. As a result of the recommendations an allocation of $2,000 for the year 1954 had been recommended to the Executive Board of International Council of Scientific Unions for the printing of one extra sheet for that year and that formal approval could be confidently expected at the meeting of the Board in July 1953. Similar allocations for both the years 1955 and 1956 depended on

the global sum voted to the International Council of Scientific Unions by the Conference of UNESCO to be held in November 1954. It was therefore considered wise not to look further ahead for the present than the year 1956.

The following is the proposed plan for the production of new sheets of the Bathymetric Chart:

Year	1954		1955		1956	
	I.H.B.	*I.C.S.U*	*I.H.B.*	*I.C.S.U.*		
Charts to be issued	B'IV	B'III	C'II	B'II*	A'I†	A'IV†
Estimated cost of printing	$2,000	$2,000	$2,000	$2,000	$2,250	$2,250

* Completes 3rd Edition, except for Polar Section.
† 4th Edition.

The above estimated cost of printing is based on the present rate of exchange between French francs and U.S. dollars.

In this connection it was emphasized that the production of both sheets A'I and A'IV (4th Edition) in 1956 might prove impossible without extra staff, which the Bureau could not employ before 1957 at the earliest, unless sufficient sums were forthcoming from interested organizations. It is hoped that it can be arranged between the International Council of Scientific Unions and UNESCO that the 1956 allotment may be carried forward to 1957.

It will thus be seen that the Bureau will issue three new sheets this year, the cost of which will be met from the funds of the Bureau – and we propose issuing two new sheets in each of the years 1954-6, the cost of one being met by the International Hydrographic Bureau and the cost of printing the other by allotments received from the International Council of Scientific Unions. The second sheet each year will bear the following legend:

> " Prepared and published by the International Hydrographic Bureau and printed at the expense of the International Council of Scientific Unions out of funds derived from UNESCO."

Of the three new sheets to be issued this year, sheet B'I, will shortly be distributed. Sheets BII and BIII have not yet been completed owing to the difficulty the printers have found in adjusting the hypsometry to the new coast line, which differs very considerably from that shown on the 2nd Edition.

It is difficult for the International Hydrographic Bureau to present the Bathymetry in a form which will fully satify the various scientists who we hope will make use of the chart. For instance, biologists are chiefly interested in the animal life in the seas and the fishery development, depending on depth and geographical position; the hydrologists on the chemical composition of sea water, the behaviour of ocean tides and currents and the up-welling of deep water, the temperature and salinity distribution and other properties of sea water; geophysicists and geologists on the evolution of the earth's crust, formation of the sea floor and modification of the coast-line; geographers in the study of the sea from many aspects; and the Hydrographers with the depths of the oceans and seas and the currents and tidal streams therein, from a navigational point of view. Each of these scientists might well have very different ideas as to how the depth-contours should be drawn, especially in

those vast areas still imperfectly explored. This difficult problem has always been fully appreciated since we first took over the responsibility of preparing a 3rd Edition twenty years ago, and we have therefore, after plotting all available soundings, invariably consulted the maps or plans accompanying the Reports of Oceanographic Expeditions and other publications before drawing the contour lines. We realize that we are not infallible, and would welcome suggestions and criticisms of our work before the final printing. No doubt the International Joint Commission on Oceanography could suggest the name of some scientific expert who in their opinion could look at the first proof of each new sheet objectively and without unduly delaying the final printing. We have already done this in the case of sheet B'1 which we sent to Dr. H. F. P. HERDMAN during the early stages of its production and whose valuable suggestions were accepted.

The question of making the General Bathymetric Chart of the Oceans better known to scientists, the public and shipping companies was again discussed at the Monaco meeting of the International Joint Commission on Oceanography a year ago when it was agreed that members would do their best to supply the International Hydrographic Bureau with library lists and other suggestions to increase the sale and improve the scientific value of the Chart. Since then the Bureau has been actively engaged in studying this question, especially as regard the cost of the fascimile reproduction of certain sheets, if and when found necessary. The most favourable estimate received is roughly 500,000 French francs for 200 copies, as compared with 900,000 francs for producing a new sheet. We then considered the possibility of placing the chart on sale by booksellers (whereas previously it had only been supplied directly from the International Hydrographic Bureau). Acting on the advice of Dr. R. FRASER, we got in communication with a firm in London, but so far it has not been possible to come to any satisfactory arrangement. Members of the International Joint Commission on Oceanography are asked to make the chart better known, especially in Universities and Schools.

We have recently slightly raised the prices of the chart as suggested at the Monaco meeting.

The following is the present state of sales:

3RD EDITION OF THE GENERAL BATHYMETRIC CHART OF THE OCEANS

1. Subscribers to full set before 1939: 34
   remaining after 1945: 9
2. Purchasers of full set without replacement sheets:
   From 1946 to 1949: 23
   From 1950 to June 1953: 14
3. Purchasers of single sheets:
   In 1950: 22
   In 1951: 73
   In 1952: 108
   In 1953 (30 June): 63

With reference to Recommendation n° 3 of the International Joint Commission on Oceanography the Bureau has made a careful study of various processes for the

reproduction of the General Bathymetric Chart Plotting Sheets. In most cases the soundings were plotted in pencil only and in others in coloured chalks, and many of course were very old; however a most successful means has been found whereby the reproduction, on approximately the same scale and in black only is as clearly decipherable as the original.

The Bureau is therefore now in a position to supply, for expert use at short notice on request, copies of each plotting sheet brought up to date from the latest soundings received at a cost of approximately one pound sterling per sheet.

The following grants have been received in 1953 towards the cost of producing new sheets of the General Bathymetric Chart of the Oceans:

From Marsh Fund Committee, National Academy of Sciences, U.S.A.	$125
From the " Challenger " Society, London	£25
From the Office de la Recherche Scientifique d'Outre-Mer, France	F.F. 20,000

In addition to the above, the International Hydrographic Bureau has been informed that a sum of $2,000 has been allocated by the International Council of Scientific Unions for the printing of one extra sheet of the Bathymetric Chart in 1954. Similar allocations for the years 1955 and 1956 will depend on the global sum voted to the International Council of Scientific Unions by the Eighth General Conference of UNESCO in November 1954.

On behalf of the Directing Committee of the International Hydrographic Bureau, the writer expresses his deep appreciation of these grants.

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DISCUSSION

Commander Ritchie, R.N. I would like to ask Admiral Nares two questions:

1. We are very pleased to see such a clear cut programme for producing two bathymetric charts each year and we should now like to know what is the latest date of producing data to be included in these charts. If we can have such a date to work to then Hydrographic Offices can concentrate on preparing the data for the specific sheets to be produced.

2. I am interested to know if the policy of showing soundings is to be the same for each sheet. What is the policy for showing on what density of soundings fathom lines are based, and is this to be the same for all charts ?

Admiral Nares replied:

1. Up to the end of March of each year would be suitable.

2. (Admiral Nares described the dotting of fathom lines, and said that fewer soundings are being shown than formerly.)

Mr. Stigant asked: How the I.H.B. wished to have new sounding data reported to them, e.g. should the soundings be plotted on a chart or should lists be sent in showing the latitude and longitude at each sounding ?

2. Could it be assumed that, in future, the I.H.B. Bathymetric Charts would show the nomenclature for submarine features recommended by Dr. Wiseman's (N.O.B.) Committee ?

Admiral Nares replied: 1. That the I.H.B. preferred if possible that the latitude and longitude of each sounding be supplied as it may have to be plotted on a chart of scale larger than the one sent in by the observer.

2. Names on the sea portion of the sheets are restricted as much as possible so as not to obliterate the depth contours, but in deciding what names will be intended in future editions of the various sheets the N.O.B. nomenclature would be used as a basis.

Commander Ritchie, R.N.: As regards sounding lists, I would like to point out that commercial sounding sets go to a depth of only about 600 fathoms. Only surveying ships and research vessels are equipped to supply ocean sounding data. The number of these vessels is few and we must give them every encouragement to take soundings. The compilation of sounding lists on board ship is laborious and the British Hydrographic Department has therefore produced a series of 600 1/1 Million plotting sheets for use as sounding sheets at sea and for forwarding such results to office. The officers have then only to plot their course on these sheets and ink in the corrected soundings. These sheets are on the same scale as the I.H.B. plotting sheets and we intend supplying the bulk of our results to I.H.B. in this form.

In reply **Admiral Nares** described the drawing of the fathom lines, by firm lines where they are considered fully justified by the number of soundings available and by dotted lines where such is not the case. He also confirmed that, in accordance with the proposal of the Brussels Conference 1951 the number of soundings appearing on the published sheets have been considerably reduced and that generally only the maximum and minimum are shown. This is the policy for each new sheet, unless future Conferences suggest otherwise.

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Paper read at Symposium of the Joint Commission on Oceanography at Liverpool, 1-2 September 1953

Titan in Tiefseesedimenten

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Summary—There are four sources of titanium in deep-sea deposits: (1) The colloidal and suspended material in sea water derived from terrestrial weathering; (2) Chemically relatively undecomposed residues from the weathered terrestrial material transported by currents; (3) Volcanic ash and dust carried both by water and wind; (4) The migration of titanium in sediments, shown by the neo-formation of anatose (TiO^{-}).

All four sources have varied into time; and, since the last glacial period, there have been variations in titanium content. One must, therefore, be extremely cautious in the use of titanium-content as a means of determining the rate of sedimentation in the inorganic content of sediments.

Der Titangehalt der Tiefseesedimente ist in der letzten Zeit verschiedentlich dazu benutzt worden, um Aussagen über die Sedimentationsgeschwindigkeit der nicht organogen gebildeten Sedimentanteile zu machen (KOCZY 1950, ARRHENIUS 1952). Es scheint deswegen nützlich, sich einmal zu überlegen, wie der Titangehalt der Tiefseesedimente zustandekommt.

Wenn wir den Gehalt eines Elementes in einem Sediment betrachten wollen, so ist es nötig, sich zunächst einmal darüber klar zu werden, wie das Element in das Sediment hineinkommt. Letzten Endes stammt das Titan der Sedimente aus den Eruptivgesteinen, in denen es stets, aber in wechselnder Menge vorkommt. Im allgemeinen sind die sauren Gesteine titanärmer als die basischen. Für unsere Betrachtungen genügt es, wenn wir die zwei verbreitetsten Typen, die granitischen Tiefengesteine und die basaltischen Ergussgesteine, betrachten. In der folgenden Tabelle sind drei saure Tiefengesteine, ein Tonalit, ein Granit und ein Granodiorit, nach den Untersuchungen von NOCKOLDS und MITCHELL (1948) aufgeführt. Besonders wichtig für die Sedimentbildung ist die Frage, in welchen Bestandteilen dieser Eruptivgesteine das Titan steckt. Wie die Tabelle zeigt, ist ein beträchtlicher Anteil des Gesamttitangehaltes des Gesteins in den Biotiten und Hornblenden und in dem selbständigen Titansilikat Titanit enthalten, also 2/3 bis 1/2 des TiO_2 in Silikaten, der Rest im Eisenerz.

In den basaltischen Gesteinen sind die wichtigen selbständigen Titanminerale die oxydischen Erze Ilmenit und Titanomagnetit. Dr. WEDEPOHL war so freundlich, auf meine Bitte einen Feldspatbasalt vom Hohen Hagen und einen Trachydolerit vom Backenberg, beide in der Nahe von Göttingen, auf die Verteilung des Titans in den Mineralen zu untersuchen. Bei dem Feldspatbasalt mit insgesamt 2,26% TiO_2 sind 65-70% des gesamten TiO_2 an das oxydische Erz gebunden. Der Rest steckt in den Augiten. Bei dem Trachydolerit des Backenberges, bei dem 3 Proben mit 1,98, 2,32 und 2,73% Gesamt-TiO_2 analysiert wurden, ergab sich, dass im Erz nur 55-60% des TiO_2-Gehaltes stecken, der Rest in den Augiten. Zu diesen Angaben passt grössenordnungsmässig die ältere Mitteilung von G. VON HEVESY (1931), der

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in seiner Standardmischung von Eruptivgesteinen fand, dass die Erzfraktion mehr als 2/3 des gesamten Titangehaltes bedingt. In basaltischen Gläsern (Sideromelan) kann man nach HOPPE (1940) mit etwa 1-2% TiO_2 rechnen. Asche vom Vatnajokull in Island enthalt 2,51 und 2,83% TiO_2 (nach BARTH, zitiert bei HOPPE, 1940). In sauren Gläsern, Obsidian und Bimstein, ist sehr viel weniger TiO_2, 0,1-0,4% (WRIGHT 1915).

Tabelle 1

Granit (*Adamellit*)		
Gesamtgehalt :	0,38% TiO_2	
darin 7% Biotit mit 3,66% TiO_2		0,256% TiO_2
< 2% Titanit + Eisenerz		0,124% TiO_2
Tonalit		
Gesamtgehalt:	1,03% TiO_2	
darin 11% Biotit mit 3,84% TiO_2		0,42% TiO_2
5% Hornblende mit 1,73% TiO_2		0,09% TiO_2
< 2% Titanit + Eisenerz		0,52% TiO_2
Granodiorit		
Gesamtgehalt:	1,13% TiO_2	
darin 11% Biotit mit 3,28% TiO_2		0,36% TiO_2
7% Hornblende mit 0,96% TiO_2		0,07% TiO_2
0,5% Titanit mit 40% TiO_2		0,20% TiO_2
< 1,5% Eisenerz		0,52% TiO_2

Was geschieht nun mit dem Titan bei der Verwitterung ? Nach dem, was wir sonst über die Verwitterung der Silikate wissen (CORRENS 1940), können wir annehmen, dass auch das Titan bei der Auflösung des Silikatgitters zunächst in Ionenform in Lösung geht. Etwas stabiler als die Silikate dürfte der Ilmenit sein. Wenn man auch erwarten kann, dass das Ti im Augenblick des Zerfalls als Ion in Lösung geht, so wird jedoch seine Lebensdauer nach allem, was über die Chemie des Titans bekanntist, bei Anwesenheit von Sauerstoff sehr kurz sein. Noch weniger als das Aluminium und das Eisen kann das Titan in echter Lösung weit verfrachtet werden. Das Titan fällt sofort als Oxydaquat aus, das bei den bei der Verwitterung vorkommenden p_H-Werten ausserordentlich wenig löslich ist und sich allmählich in eines der Oxyde, Anatas oder Rutil, umwandelt. Uber die Bildungsbedingungen der beiden Modifikationen wissen wir noch sehr wenig. Im Laboratorium scheinen SO_4- und PO_4- Ionen die Ausscheidung von Anatas zu begünstigen. Diese wirken auch verzögernd auf die Umwandlung von Anatas in Rutil. Löslichkeitsbestimmungen in Abhängigkeit vom p_H an feinstkörnigem synthetischen Anataspulver durch BREMER (1946) ergaben bei p_H 4 (H_2SO_4) noch unter 0,01 mg/L TiO_2, bei p_H 6 konnte kein Titan in der Lösung nachgewiesen werden.

Die Anreicherung des Titans bei der Verwitterung ist schon lange bekannt. Man hat sie meist allein als Rückstand durch die geringe Löslichkeit des TiO_2 zu erklären versucht. Neuerdings konnte SHERMAN (1952) an hawaiischen Böden zeigen, dass das Ti bei der Verwitterung wandern kann und Anatas gebildet wird, dass Konkretionen in den humösen eisenlateritischen Böden entstehen. Die Anreicherung kann hier bis zu 25% TiO_2 gehen. Es ist anzunehmen, dass unter reduzierenden Bedingungen das Titan als dreiwertiges Titan gelöst werden und wandern kann. Dreiwertige Titanverbindungen wie $TiCl_3$ sind ja unter Sauerstoffabschluss recht stabil. Bei Oxydation fällt vierwertiges Titan als Oxydaquat aus. Wie weit auch

die bekannte Anreicherung von TiO_2 in Lateriten und Bauxiten mit solchen Wanderungen zusammenhängt und nicht einfach eine Rückstandsbildung ist, müsste noch untersucht werden. Im gemässigten Klima fand VON ENGELHARDT (1940) in einem mecklenburgischen Podsolbodenprofil in den feinsten Fraktionem im Bleichsand (A_2) 2,4% TiO_2, im Ortstein (B_1) 1,0%, im unveränderten braungelben Sand (B_1) nur 0,4% TiO_2. Auch hier wird man die Anreicherung auf Wanderung zurückführen müssen. PILLER (1951) fand eine Anreicherung von Anatas und vielleicht auch von der dritten Modifikation, dem Brookit, in den Verwitterungsprofilen des Brocken-Granits von St. Andreasberg. Bei rein mechanischer Verwitterung, wie sie in Finnland von SALMINEN (1938) untersucht worden ist, reichert sich das Titan in der aus Glimmern bestehenden feinsten Fraktion an. Die dunklen Glimmer können, wie schon oben beim Biotit erwähnt, beträchtliche TiO_2-Mengen enthalten. Je nach der Art der Verwitterung wird also Ti mehr in Form von meist sehr feinkörnigen Neubildungen oder in den chemisch nicht oder wenig veranderten Verwitterungsresten zum Abtransport bereitstehen.

Aus diesem Uberblick über die Verwitterungsbedingungen des Titans geht hervor, dass es sehr unwahrscheinlich ist, dass nennenswerte Mengen von Titan in Lösung ins Meerwasser geraten. Die älteren Analysen des Meerwassers cheinen diese Ansicht auch zu bestätigen. Titan wurde früher nicht nachgewiesen, und I. und W. NODDACK (1939) geben an, dass der Gehalt kleiner als 0,5 mg/t sein sollte. Demgegenüber haben BLACK und MITCHELL im vergangenen Jahr eine Mitteilung veröffentlicht, nach der sie 6-9 mg/t Ti, also 10-15 mg/t TiO_2 gefunden haben. Nach mündlicher Mitteilung von MITCHELL kann es sich dabei sehr wohl um kolloidales TiO_2 gehandelt haben. Dass das Meerwasser kolloidales Material enthielt, dafür spricht auch der sehr hohe Mn-Gehalt > 3000 mg/t, während sonst 5 mg/t angegeben werden. Auch dann ist noch verwunderlich, dass dieses kolloidale TiO_2 bisher sonst nicht gefunden wurde. Dass das bei der Verwitterung entstehende Titanoxydaquat sowohl als Kolloid wie auch als Suspensoid ins Meer transportiert werden kann, ist zu erwarten, ebenso wie das beim Eisen und Aluminium der Fall ist. Hier haben wir also eine der Quellen für den Titangehalt der Sedimente. Ausser solchen Verwitterungsneubildungen trägt chemisch nicht völlig verwittertes Material, das durch die Flüsse ins Meer gebracht wird, zum Titangehalt der Sedimente bei. Wie wir gesehen haben, kann es sich bei diesen Verwitterungsresten sowohl um Erzkörnchen als auch um Glimmer, Hornblende und Augite handeln. Neben dem Wassertransport ist auch der Lufttransport durch den Wind zu berücksichtigen. Dabei wird man annehmen dürfen, dass der Ti-Gehalt an terrigenem Staub nicht wesentlich über der Durchschnittsmenge der Sedimente liegt, so gibt z.B. LEUCHS (1932) zwei Staubanalysen mit 0,58 und 0,68% TiO_2. Wesentlich mehr ins Gewicht fallen zweifellos die vulkanischen Aschen basaltischer Herkunft, die sowohl Augite wie auch Glaspartikel, die titanhaltig sind, liefern. Schliesslich ist auch noch die Frage zu erörtern, wieweit das Titan in den Sedimenten wandern kann.

Betrachten wir unter diesen Gesichtspunkten die Tiefseesedimente in ihrer chemischen und mineralogischen Zusammensetzung. Ich halte mich dabei im wesentlichen an die von mir und meinen Mitarbeitern untersuchten Proben der Meteor-Expedition im mittleren Atlantischen Ozean. Als Mittel von 178 Titanbestimmungen wurden 0,71% TiO_2 in den kalkfrei berechneten Tiefseesedimenten gefunden. Dieser Titangehalt ist, wie Abb. 1 zeigt, unabhängig vom Kalkgehalt. Diese Abbildung 1 wurde

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so erhalten, dass die Tiefseesedimente in Kalkgehaltsklassen von je 10% $CaCO_3$ eingeteilt wurden und in jeder Klasse für sich der TiO_2-Gehalt der Sedimente – auf kalkfrei berechnet – gemittelt wurde. Dass das Titan nicht aus den Kalkschalen der Organismen stammen kann, stimmt auch mit den sonstigen Beobachtungen überein, dass Titan nicht in nennenswerten Mengen in Organismen angereichert wird. Zwar haben BLACK und MITCHELL (1952) Titan in Seetang nachgewiesen, aber der höchste von ihnen gefundene Gehalt von 308 mg Ti/t in der Trockensubstanz vermag nicht zu einer Anreicherung von Titan zu führen, ebensowenig wie die von I. und W. NODDACK angegebenen Werte für Seetiere von 1 bis 8 mg Ti/t, da die Sedimente ja etwa 4 kg Ti und mehr in der Tonne enthalten.

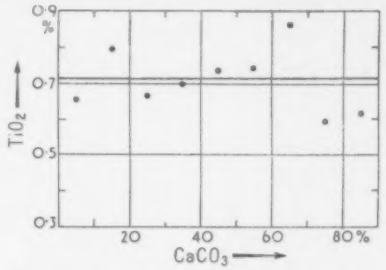

Abb. 1. Durchschnittswerte des auf das kalkfreie Sediment berechneten TiO_2-Gehaltes in %, in Abhangigkeit vom Kalkgehalt.

Eine weitere Frage ist, in welcher Form das Titan im Sediment vorliegt. Eine Untersuchung des Titangehaltes in den verschiedenen Korngrössen ergibt, dass der Gehalt an kolloidalem TiO_2, z.B. im Roten Ton der Station 305, in den feinsten Fraktionen geringer als in den gröberen ist, Abb. 2. Im Gegensatz zum Eisen und Mangan, bei denen ebenfalls die gröberen Anteile zum Gesamtgehalt beitragen, wo aber eine starke Zunahme des Gehaltes in den feinsten Fraktionen festzustellen ist, ist die Hauptmenge des Titans in den gröberen Fraktionen vorhanden. Immerhin enthält die abzentrifugierte Kolloidfraktion mit Aequivalentradius $< 0{,}1\,\mu$ noch 0,55% TiO_2. Aehnlich verhalten sich die Analyse eines Blauschlicks der Station 232, die in den Korngrössen 1-100 μ Radius 0,51% TiO_2 ergab, während die Korngrössen unter 1 μ 0,38% TiO_2 enthalten, sowie viele Untersuchungen an anderen Tonen, die nicht aus der Tiefsee stammen. Man wird also neben den feinstkörnigen Verwitterungsneubildungen den grobkörnigen Verwitterungsresten und den vulkanischen Aschen einen wesentlichen Anteil am Titangehalt der Tiefseesedimente zuschreiben müssen. Diese Bestandteile wurden auch in vielen Fällen bei der mineralogischen Untersuchung der Sedimente nachgewiesen. Wenn der Titangehalt der Sedimente auch von diesen Komponenten abhängt, so ist zu erwarten, dass in der Nachbarschaft von Vulkangebieten in Abhängigkeit von Wind und Strömung höhere Titangehalte auftreten als in weiterer Entfernung. Das zeigt Abb. 3, in der durch ausgefüllte Punkte im mittleren Atlantischen Ozean die Stationen eingetragen sind, in denen

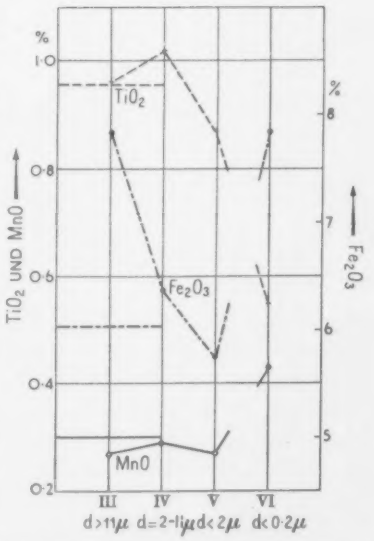

Abb. 2. Verteilung von TiO_2, MnO und Fe_2O_3 auf die Korngrössenfraktionen des Roten Tons der Meteorstation 305.

ein Titangehalt von mehr als 0,7% TiO_2 auf das kalkfreie Sediment berechnet, gefunden wurde. Die Titangehalte in der Umgebung der Kapverdischen Inseln und von Fernando Po liegen über dem Durchschnitt. Eine strenge Abhängigkeit wird man nicht erwarten dürfen, weil auch das terrigene Material unter Umständen etwas höheren Titangehalt mitbringen kann, z.B. aus der Verwitterung lateritischer Böden.

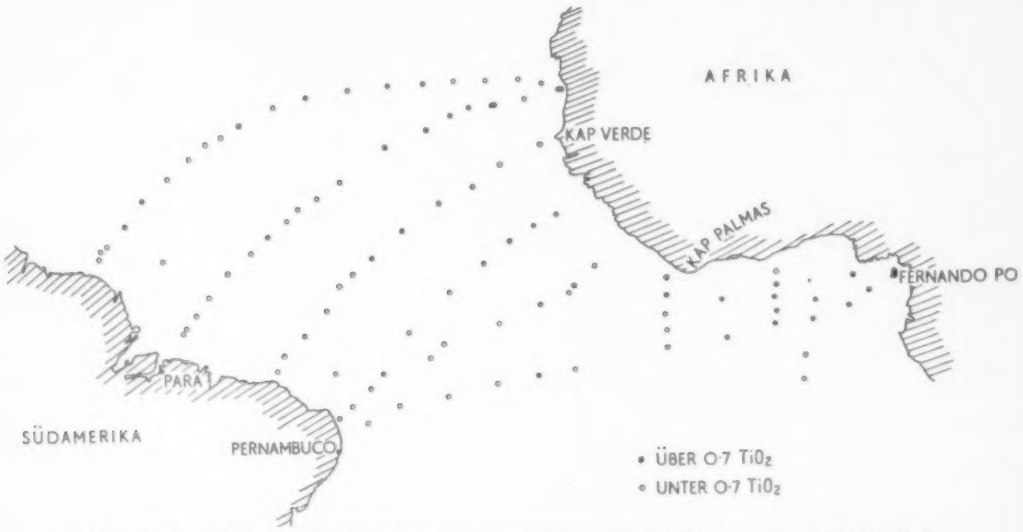

Abb. 3. TiO_2-Gehalt der Oberflachenproben im mittleren Atlantischen Ozean auf kalkfreies Sediment berechnet. O unter 0,7% TiO_2; ● Juber 0,7% TiO_2

Es kommt ferner hinzu, dass die mineralogische Untersuchung der Sedimente gezeigt hat, dass das Titan in den Sedimenten wandern kann. Es wurden nämlich in den Meteor-Sedimenten in 14 Proben Neubildungen von Anatas beobachtet. Solche Neubildungen sind übrigens auch in Kaolinen (NAGELSCHMIDT *et al.* 1949) und im limnischen tertiaren Ton von Grossalmerode (LIPPMANN 1952) gefunden worden. Die Entstehung des Anatas kann man wohl in Analogie zu der oben erwähnten Neubildung in hawaiischen Böden annehmen. Gerade in den feinkörnigen tonigen Tiefseesedimenten kommt es durch die Einbettung organischen Materials im Sediment auch dort zu reduzierenden Vorgängen, wo das Bodenwasser sauerstoffreich ist. Das tonige Sedimentmaterial verhindert einen Austausch mit dem Bodenwasser. Das ist aus den Blauschlicken in der Küstennähe mit ihrem relativ hohen Gehalt an organischer Substanz schon länger bekannt, aber auch im Roten Ton finden sich Hinweise darauf, unabhängig vom Titangehalt, nämlich durch die Bildung von Eisenkarbonat, das nur unter reduzierenden Bedingungen entstehen kann.

Wie weit der Titangehalt der Manganknollen auf solche Wanderungen zurückzuführen ist, und wie weit er durch Aufnahme aus dem Meerwasser stammt, ist zur Zeit noch nicht mit Sicherheit zu beantworten. Eine Analyse von Gümbel an einer Manganknolle der *Challenger* (zitiert bei MURRAY und RENARD 1891) von 1878 ergab 0,66% TiO_2, eine von Gibson von Knollen der *Challenger*station 285 (zitiert ebendort) 0,13% und eine Analyse von Greiner an Mn-Knollen der Valdiviastation

87 im südlichen Atlantik 1,05% TiO_2. Dr. P. SCHNEIDERHÖHN hat auf meine Bitte die äusserste Rinde einer Knolle der *Challenger*station 286 analysiert und 0,64% TiO_2 gefunden, dazu 15,02% SiO_2 und 17,88% Fe_2O_3 (Gesamteisen).

Aus den bisherigen Ueberlegungen und Beobachtungen können wir folgende Schlüsse ziehen :

Wir müssen damit rechnen, dass der Titangehalt einer bestimmten Sedimentprobe durch das Zusammenwirken verschiedener Vorgänge entsteht, und dass jeder dieser Vorgänge zu verschiedenen Zeiten verschieden gewirkt haben kann. Die Wanderung im Sediment z.B. wird so lange vor sich gehen können, als noch reduzierende Substanz im Sediment vorhanden ist und auch nur soweit erfolgen, wie reduzierende Bedingungen bestehen. Der Titangehalt des vom Festland ins Meer gebrachten Materials hängt wesentlich von den klimatischen Bedingungen ab, die z.B. im Glazial sicherlich andere waren als heute. Die Zufuhr vulkanischen Materials, die, wie gezeigt wurde, eine wesentliche Rolle spielen kann, variiert ebenfalls sehr stark mit der Zeit. Betrachtet man den Titangehalt der Proben in Abhängigkeit von der Tiefe, so findet man sehr starke Schwankungen. Bereits innerhalb von Proben, die nach W. SCHOTTS Foraminiferenuntersuchungen im Postglazial liegen, kann sich der Titangehalt – immer auf kalkfreies Sediment bezogen – sehr ändern, und zwar sowohl als Abnahme wie als Zunahme. Erst recht ist dies der Fall bei Proben, die ins letzte Glazial hinabreichen. Solche Schwankungen weisen auch die Analysen der Proben, die BRADLEY und Mitarbeiter (1942) aus dem nördlichen Atlantischen Ozean mitgeteilt haben, auf.

Meine Bemerkungen beziehen sich nur auf den relativ kleinen Atlantischen Ozean. Es mag sein, dass in dem weiträumigen Pazifischen Ozean der Einfluss der Küsten und auch der vulkanischen Beimengungen an manchen Steller geringer ist. Immerhin scheint mir auch hier Vorsicht geboten, wenn man das Titan als eine konstante Grösse für die Zufuhr des terrigenen Materials betrachten will.

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NACHTRAG WÄHREND DER KORREKTUR

Table

TiO_2-Gehalte auf den kalk- und kieselfreien Rest der Sedimente berechnet

Meteor Station		*nicht kalk. Rest*	*% Kiesel im Rest*	*nicht organogen Gesamt %*	*darin % TiO_2*	*Alter nach* SCHOTT
217	o	47,8	19,4	38,5	1,14	Rezent
	u	47,8	9,5	47,7	0,65	Interglazial
218	o	44,2	8,8	40,3	0,86	Rezent
	u	55,9	0,9	55,4	0,61	Glazial
225	o	40,2	27,1	29,3	0,61	Rezent
	u	42,9	41,8	25,0	1,20	Glazial
228	o	94,6	25,4	70,6	0,62	Rezent
	u	91,3	13,6	78,9	1,06	Postglazial
229	o	97,9	2,9	95,3	0,58	Rezent
	u	98,8	1,3	97,5	1,03	Postglazial
230	o	98,7	16,3	82,8	1,33	Rezent
	u	98,2	3,3	95,0	0,78	Glazial
231	o	71,7	12	63,1	1,03	Rezent
	u	96,6	2,6	94,1	0,37	Glazial
233	o	48,4	4,3	46,3	1,14	Rezent
	u	85,4	16,1	69,7	0,43	Glazial
234	o	50,6	6,8	47,2	0,93	Rezent
	u	96,4	0,5	95,9	0,54	Glazial
235	o	93,3	9,4	84,5	1,25	Rezent
	u	95,9	1,2	94,8	0,63	Glazial
241	o	18,3	37,2	11,5	0,61	Rezent
	u	25,6	58,2	10,7	1,31	?
266	o	59,6	6,7	55,6	0,44	Rezent
	u	94,7	1,6	93,2	0,99	Glazial

Herrn Dr. G. Arrhenius, dem ich die Korrekturbogen des vorstehenden Vortrages zugeschickt hatte, verdanke ich den Hinweis darauf, dass der Titangehalt für kalkfreies Sediment berechnet nicht ohne weiteres gleich dem Titangehalt der nichtorganogenen, also der terrigenen Bestandteile gesetzt werden darf. Ausser dem Kalkgehalt kann auch organische Kieselsäure verdünnend wirken. Darauf habe ich selbst immer wieder hingewiesen, zuletzt 1950*. Es ist deshalb gewiss nützlich, wenn ich in der folgenden Tabelle Titangehalte auf das von Kalk und organischer Kieselsäure freie Sediment berechnet mitteile. Die Werte sind aus etwa 50 Angaben des Meteor-Werkes, bei denen zugleich quantitative Werte für TiO_2 und für organische Kieselsäure vorliegen, in der Art ausgewählt, dass alle hohen Gehalte an Kieselorganismen berücksichtigt wurden. Die Tabelle zeigt deutlich, dass der Gehalt an TiO_2 der rein terrigenen Komponente sowohl von Ort zu Ort als auch nach der Tiefe, d.h. zwischen der heutigen Zeit und der Postglazial- und Interglazialzeit, sehr erhebliche Schwankungen aufweisen kann.

*Correns, C. W. (1950), Faktoren der Sedimentbildung, erläutert an Kalk- und Kieselsedimenten. *Dtsch. Hydrogr. Ztschr.*, Bd. 3, H.1/2, S.83-88.

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Variation de la teneur en Oxygène de l'Eau au proche voisinage des sédiments

JEAN BROUARDEL et LOUIS FAGE

AU cours de l'été 1952 un certain nombre d'opérations de carottage avaient été faites en face de Monaco en vue d'étudier la répartition du carbone organique dans les sédiments et la teneur en oxygène de l'eau à leur contact.

Le carottier utilisé était un BUCHANAN. Celui-ci, tout en cuivre, comprend deux étages, le premier, carottier proprement dit, constitué par un tube destiné à pénétrer le sédiment, le second formant réservoir séparé du premier par un clapet. A la descente de l'appareil, l'eau circule dans celui-ci; à la remontée, elle y reste emprisonnée, sans subir d'échanges avec l'extérieur, l'extrémité inférieure de l'appareil étant bouchée par la carotte, l'extrémité supérieure obturée par un clapet maintenu par une petite masse de plomb, libérée par inertie de son tenant lorsque l'appareil touche le fond. La pression de l'eau, due à la vitesse de remontée, s'ajoute ensuite à l'action de ce plomb pour maintenir le réservoir fermé.

Lors de quelques-uns des carottages nous avions fait, à chaque remontée de l'appareil, deux déterminations de l'oxygène dissous, l'une dans l'eau recueillie immédiatement au-dessus de la carotte, l'autre dans l'eau du réservoir à une quarantaine de centimètres du sédiment.

Les résultats relatifs aux stations pour lesquelles cette double détermination a été faite figurent au tableau 1.

Tableau 1

Profondeur	*Teneur en O_2 de l'eau au contact de la carotte*	*Teneur en O_2 de l'eau dans le réservoir au-dessus de la carotte*	*Différence*
220 m.	6·67	6·90	+ 0·23
350 m.	6·45	6·57	+ 0·12
316 m.	6·25	6·65	+ 0·40
491 m.	6·05	6·02	=
742 m.	5·90	6·35	+ 0·45
741 m.	5·70	5·98	+ 0·28
1081 m.	5·55	5·85	+ 0·30
675 m.	5·54	5·97	+ 0·43
900 m.	5·53	5·62	+ 0·09
667 m.	5·48	5·77	+ 0·29
		Moyenne	+ 0·30

Les teneurs en O_2 sont exprimées en milligramme par litre (mg/l).

La teneur en oxygène de l'eau au contact de la carotte était donc plus faible que celle de l'eau située au-dessus. Pour ces dix expériences elle était en moyenne inférieure de 0·30 mg/l représentant une différence d'environ – 5%.

Il convenait alors de vérifier par une méthode plus rigoureuse l'existence de cette notable et rapide chute de la teneur en oxygène de l'eau au proche voisinage du sédiment.

Tout d'abord, le carottier BUCHANAN a subi les modifications suivantes:

(*a*) La partie du carottier destinée à s'enfoncer dans la vase a été raccourcie et élargie au diamètre du corps même de l'appareil pour permettre une meilleure circulation de l'eau à la descente.

(*b*) Le réservoir a été allongé et partagé en quatre étages superposés, séparés les uns des autres par des clapets de même type que celui du BUCHANAN primitif permettant ainsi d'avoir une succession de tranches d'eau superposées et isolées les unes des autres à la remontée.

(*c*) Une masselotte de plomb a été fixée au bout d'un levier sur la partie supérieure du carottier permettant par inertie, lorsque le carottier est arrêté dans sa course par son choc sur le sédiment, de libérer, à coup sur, le plomb destiné à maintenir l'obturation du clapet supérieur, cela quel que soit l'angle sous lequel l'appareil frappe le fond.

(*d*) Tout l'ensemble de l'appareil a été recouvert extérieurement d'un revêtement de matière plastique destiné à éviter le réchauffement de l'eau au cours du passage de l'appareil, à sa remontée, dans les couches plus chaudes de surface, et à sa sortie de l'eau, lors des prélèvements.

(*e*) Enfin, modification plus importante, toute la surface interne de l'appareil a été revêtue d'une couche de silicone afin d'éviter tout phénomène d'oxydation du métal.

Avec ce nouvel appareil une nouvelle série de carottages a été entreprise, mais, au bout de quelques-uns de ceux-ci il a été constaté que, si le revêtement de silicone tenait parfaitement sur toute la partie interne du corps en cuivre du carottier, il n'en était pas de même à sa partie inférieure où le choc sur le sédiment, puis le frottement de la carotte l'enlevaient rapidement. Cette partie ayant été réalisée en fer, on était en droit de se demander si, pendant le temps de remontée de l'appareil et celui (d'ailleurs très court) des prélèvements, un phénomène d'oxydation dû au métal n'intervenait pas dans cette partie du carottier, phénomène capable de faire perdre toute signification aux résultats.

La vérification a été faite au laboratoire, de la façon suivant:

La partie inférieure de l'appareil maintenu vertical, était raccordée par un tube de caoutchouc à un robinet d'eau de mer provenant de la cuve d'alimentation de l'aquarium. Pendant quelques instants on laissait l'eau s'écouler, réalisant ainsi une opération analogue à celle qui se produit lors de la descente du carottier dans la mer, puis l'arrivée d'eau était fermée et le plomb d'obturation du clapet supérieur déclanché. Au bout d'un certain temps, variant suivant les expériences de 1 à 15 minutes, correspondant à la durée de séjour de l'eau dans l'appareil lorsqu'on le remonte de fonds de 120 à 1800 m.,† nous dosions l'oxygène de l'eau contenue dans les différents étages.

Le tableau 2 donne le résultat de ces expériences.

On voit tout d'abord, pour les quatre étages supérieurs, que les différences de teneur en oxygène dans chaque série d'expérience n'excèdent pas 0·15§ de l'ordre de grandeur de l'erreur analytique possible. Sur les moyennes, la différence entre deux étages contigus ne porte que sur la seconde décimale. Il y a donc égalité du taux

† La vitesse de remontée est en effet de l'ordre de 120 m. par minute.

§ (I) Pour la première série : 0·15. Pour la 2e : 0·10. La 3e: 0·05. La 4e: 0·05. La 5e : 0. La 6e: 0·05.

d'oxygène dans les quatre étages supérieurs protégés par la couche de silicone. Par contre, à l'étage inférieur apparaît, au bout de quelques minutes, une différence systématique correspondant à – 0·6 sur la moyenne des expériences, soit à environ – 10%! Il se produit donc à cet étage une oxydation qui ferait perdre toute signification aux expériences.

Tableau 2

Durée de séjour de l'eau dans l'appareil:	1′	5′	5′	10′	10′	15′	*moyenne* ♯ 8′
5e étage (supérieur)	6·20	6·45	6·55	6·65		6·50	6·49
4e étage	6·25	6·50	6·60	6·60	6·75	6·65	6·56
3e étage	6·35	6·45	6·65	6·65	6·75	6·60	6·57
2e étage		6·50	6·65	6·70	6·75	6·60	6·64
1e étage (inférieur)	6·35	6·20	6·90	5·90	6·30	5·75	6·06

Il fallait donc apporter au carottier une nouvelle modification susceptible d'empêcher ce phénomène. Pour cela toute la partie inférieure a été chemisée d'un tube en plexiglas. Dans la partie supérieure, le revêtement de silicone resté intact a été conservé.

Après cette nouvelle modification l'expérience précédente a été recommencée. Les résultats obtenus alors figurent au tableau 3 de même disposition que le tableau 2.

Tableau 3

2′	2′	2′	2′	2′	5′	5′	5′	5′	10′	10′	*Moyenne* ♯ 4½′
6·85	6·86	6·78	6·80	6·72	6·30	6·72	6·64	6·72	6·41	6·45	6·66
6·89	6·84	6·78	6·79	6·80	6·42	6·60	6·75	6·71	6·36	6·42	6·67
6·87	6·90	6·84	6·82	6·80		6·60	6·60	6·67	6·45	6·52	6·66
6·90	6·81	6·70	6·77	6·77	6·43		6·64		6·47	6·52	6·67
6·90	6·83	6·70	6·70	6·81	6·45	6·68	6·66	6·77	6·36	6·50	6·67

Les différences de teneur en oxygène dans chaque série n'excèdent pas 0·15* comme dans l'expérience précédente, mais ici cette égalité de teneur s'étend à l'étage inférieur. Sur les moyennes, les différences ne portent que sur une unité de la seconde décimale. Il y a donc égalité du taux d'oxygène à tous les étages.

Les résultats de ces expériences doivent attirer l'attention de tous les chercheurs qui sont amenés à faire des prélèvements d'eau aux fins d'analyse. Il apparaît indispensable que les engins employés soient entièrement construits en matériaux inoxydables pour éviter les causes d'erreur.

Du 25 Juin au 6 Juillet 1953 nous avons alors fait avec notre nouvel appareil une série de carottages dans les sédiments vaseux par des fonds de 70 à 500 m. sur une radiale partant du Musée Océanographique de Monaco. Le tableau 4 donne les taux d'oxygène obtenus à chaque station dans les 5 étages du carottier.

Ces résultats font apparaître deux phénomènes:

* Pour la première série: 0·05. Pour la 2e: 0·09. La 3e: 0·14. La 4e: 0·12. La 5e: 0·09. La 6e: 0·15. La 7e: 0·11. La 8e: 0·15. La 9e: 0·05. La 10e: 0·11. La 11e: 0·10. Sur les moyennes: 0·01.

I. VARIATION DE LA TENEUR EN OXYGENE AVEC LA PROFONDEUR DU SÉDIMENT

Si on considère la moyenne des teneurs en oxygène obtenues dans les cinq étages du carottier à chaque station, c'est-à-dire le taux d'oxygène d'une large couche d'eau située au voisinage du sédiment, on voit qu'au fur et à mesure que celui-ci est situé plus profondément la teneur en oxygène diminue.

Tableau 4

Profondeur en m.	70	70	80	100	110	125	160	200	280	310	330	480	500	*Moyenne* #215
5e étage (sup.)	8·14	7·81	8·31	7·85	7·68	7·61	7·52	7·41	7·24	7·06	7	6·58	6·57	7·45
4e étage	8·03	8·05	7·88	7·91	7·75	7·71	7·41	7·46	7·21	7·08	7	6·62	6·45	7·43
3e étage	8·03	8·15	8·02	7·81	7·73	7·52	7·41	7·39	7·27	7·04	6·94	6·53	6·47	7·41
2e étage	8·07	8·21	7·74	7·64	7·51	7·43	7·46	7·24	7·03	6·91	6·81	6·59	6·34	7·31
1e étage (inf.)	7·79	7·63	7·57	7·45	7·18	7·11	7·05	7·15	6·77	6·56	6·66	6·47	5·76	7·01
Moyenne	8·01	7·97	7·90	7·73	7·57	7·49	7·37	7·33	7·10	6·93	6·88	6·56	6·32	7·32

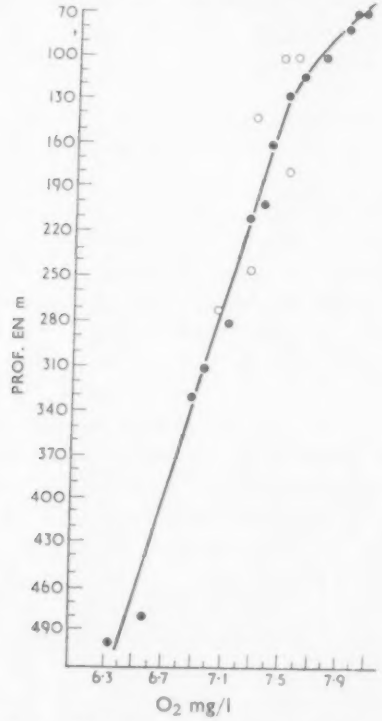

Fig 1. Variation de la teneur en O_2 dans l'eau au voisinage du sédiment.

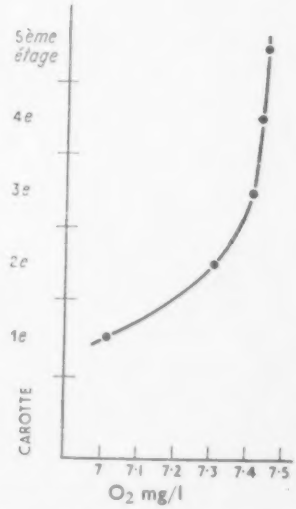

Fig. 2. Variation de la teneur en O_2 dans les 5 étages du réservoir.

L'allure de cette variation est représentée par la courbe fig. 1 obtenue en portant en ordonnées les profondeurs, en abcisses les teneurs en oxygène. Cette variation semble donc sensiblement linéaire, tout au moins à partir d'une centaine de mètres de profondeur et de l'ordre de 1/10 de milligramme pour une différence de profondeur du sédiment de 35 mètres.

2. VARIATION AU VOISINAGE DU FOND

Si on considère maintenant la teneur en oxygène de l'eau de chacun des étages successifs du carottier on voit que celle-ci s'abaisse rapidement au fur et à mesure que l'on se rapproche de la carotte. Sur les moyennes, cette différence, pratiquement nulle entre les trois étages supérieurs, apparaît entre le 3e et le 2e étage (— 0·1) et devient très nette entre le 2e et le 1er étage pour lesquels on observe une chute de teneur de — 0·3.

Sur la fig. 2 nous avons représenté cette variation moyenne. Enfin, si on considère sur les 13 séries de déterminations, les 4 séries ayant trait aux profondeurs de 70 à 110 m., puis les 4 se rapportant aux profondeurs de 125 à 280 m. et enfin celles de 310 à 500 m. on voit que pour ces trois groupes, les différences de teneur en oxygène de l'eau des 2e et 3e étages du carottier sont: — 0·10, — 0·10, — 0·08, et pour le 1er et le 2e étage: — 0·31, — 0·27, — 0·30. La chute de teneur en oxygène observée serait donc de même grandeur, quelle que soit la profondeur.

Tout phénomène d'oxydation accidentel dû à l'appareil lui-même ne pouvant intervenir ici en raison des précautions indiquées précédemment, il y a de fortes présomptions pour que cette chute du taux d'oxygène corresponde bien à un phénomène réel.

Cependant si les différents étages du carottier sont effectivement situés à 14 cm. les uns des autres, l'eau qu'ils emprisonnent n'est pas celle de ces divers niveaux dans la mer, à partir du sédiment. En effet, la circulation de l'eau dans le carottier ne se fait pas librement mais est freinée, dans une proportion que nous ne pouvons évaluer, par les clapets en caoutchouc. L'eau contenue dans les différents étages provient donc, non pas de couches distantes de 14 cm. les unes des autres mais de bien davantage. On sait que la teneur en oxygène de l'eau décroît avec la profondeur; on pouvait donc se demander si le phénomène observé ici ne faisait que traduire, à une échelle différente, déformée par la résistance intérieure de l'appareil, cette décroissance classique.

La décroissance du taux d'oxygène en fonction de la profondeur étant de l'ordre du 1/10 de mg pour une différence de niveau du sédiment de 35 m la différence de — 0·4 mg observée ici entre les deux étages extrêmes du carottier correspondrait à des niveaux distants d'environ 150 m. Il faudrait admettre alors que l'eau contenue dans l'étage supérieur du carottier proviendrait de couches situées à plus de 150 m du fond, ce qui semble peu vraisemblable.

Si les différences du taux d'oxygène observées dans les divers étages du carottier traduisent bien des différences à proximité du fond il est cependant impossible de savoir à quels niveaux au-dessus de celui-ci elles correspondent. Cela d'autant plus que les clapets, rappelons-le, en caoutchouc doivent se déformer différemment suivant leur état, la température et surtout la pression due à la profondeur, ce qui modifie la résistance offerte au passage du liquide.

Pour répondre à ces objections nous avons modifié une fois encore le carottier.

Dans ce nouvel appareil on s'est efforcé non seulement d'éviter tout phénomène d'oxydation mais encore de modifier les clapets de façon qu'ils présentent un plus libre passage à l'eau lors de la descente, tout en assurant une parfaite obturation à la remontée. De plus, ces clapets devaient être indéformables quelle que soit la pression due à la profondeur.

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Pour assurer ces conditions, l'appareil a été réalisé en matière plastique (Afcodur. Chlorure de polyvinyle rigide). Fig. 3.

La partie proprement dite du carottier se compose d'un tube de cuivre entièrement enrobé de matière plastique, se terminant à son extrêmité inférieure par un embout d'acier inoxydable destiné à pénétrer le sédiment, à son extrêmité supérieure par une bague de même acier le reliant aux étages successifs.

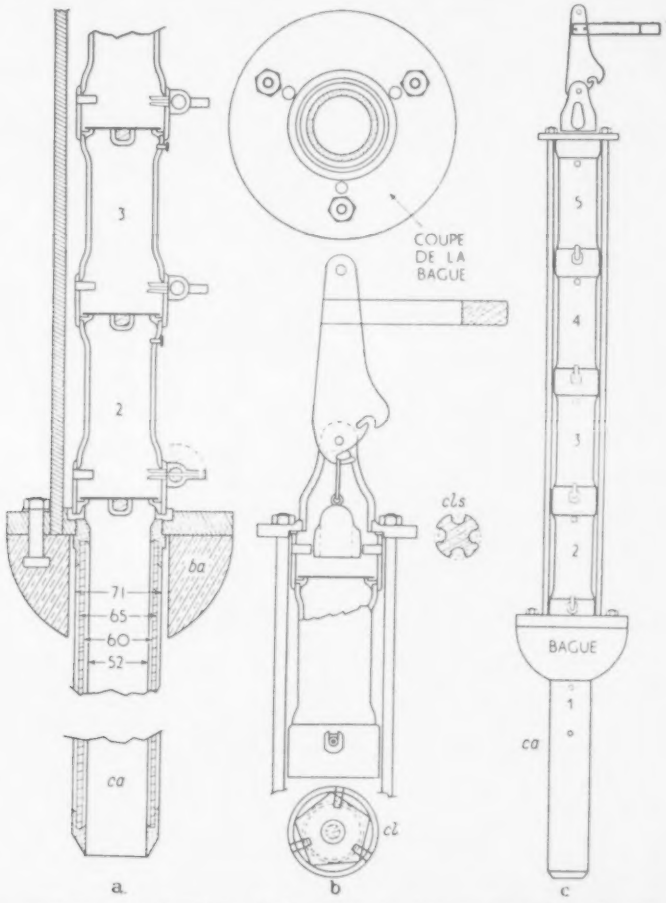

Fig. 3. (*a*) Coupe de la partie inférieure de l'appareil, ba, bague et son lest, reliant le carottier au réservoir. (*b*) Coupe de la partie supérieure; cl, un des clapets séparant les différents étages du réservoir, vu en plan. (*c*) Ensemble de l'appareil; ca, carottier proprement dit; 1, 2, 3, 4 et 5 étages successifs du réservoir séparés les uns des autres par des clapets.

Ces étages, y compris les clapets, leurs tétons de butée et les robinets de prélèvements sont entièrement en matière plastique.

Enfin, à la partie supérieure, le principe d'obturation de l'appareil primitif a été conservé. A l'extérieur de ce carottier trois tiges d'acier sont destinées à assurer à l'ensemble une grande solidité.

Avec ce nouvel appareil nous avons entrepris le 21 et le 23 Juillet de nouvelles séries de prélèvements sur la même radiale que précédemment. Malheureusement

au bout du septième carottage le filin du treuil s'est rompu et nous perdions notre appareil par 200 m. de fond.

Tableau 5

Profondeur	100	100	145	180	210	245	270	*Moyenne* ♯ 180
5e étage (sup.)	7·52	7,76	7·29	7·83	7·24	7·36	7·09	7·44
4e étage	7·50	7·45	7·39	7·66	7·36	7·37	7·17	7·41
3e étage	7·52	7·44	7·34	7·47	7·28	7·33	7·11	7·35
2e étage	7·48	7·58	7·25	7·34	7·26	7·22	7·09	7·31
1er étage (inf.)	7·29	7·53	7·05	7·20	7·09	7·04	7	7·17
Moyennes	7·46	7·55	7·26	7·50	7·24	7·26	7·09	7·34

Le tableau 5 donne les taux d'oxygène trouvés dans les cinq étages du carottier pour chacune de ces sept stations.

Ces résultats, malheureusement trop peu nombreux, apportent cependant une confirmation aux observations précédentes.

D'une part, sur les moyennes, à chaque station, on observe la décroîssance du taux d'oxygène avec la profondeur du sédiment (les points obtenus ici sont marqués O sur la courbe fig. 1; d'autre part, sur les moyennes des teneurs en oxygène à chaque étage du carottier, pour l'ensemble des stations, on retrouve la décroîssance de cette teneur mais ici cependant elle semble moins rapide (fig. 4).

Tous ces résultats concordants semblent donc bien confirmer le fait que, dans la couche explorée, la diminution du taux d'oxygène, lente avec la profondeur, devient plus rapide au voisinage du sédiment.

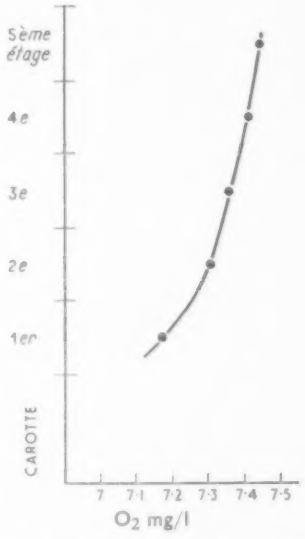

Fig. 4. Variation de la teneur en O_2 dans les 5 étages du réservoir.

DÉTERMINATION " APPROXIMATIVE " DE L'ÉPAISSEUR RÉELLE DE LA COUCHE D'EAU PRÉLEVÉE PAR LE CAROTTIER

Nous avons essayé de préciser l'épaisseur de la couche explorée en cherchant à avoir au moins une approximation des hauteurs au-dessus du sédiment auxquelles pouvait effectivement correspondre l'eau contenue dans les divers étages de notre nouveau modèle de carottier.

La vitesse de descente (2 m/s.) du carottier engendre à sa partie inférieure une pression dynamique $H = \frac{\alpha v^2}{2g}$ qui a pour conséquence de soulever les 5 clapets successifs et de compenser la perte de charge résultant de la circulation de l'eau dans l'appareil.

La pression dynamique correspondant à 2 m/s. (avec $d \sharp 1$) est de 0·200 m de colonne d'eau en chiffres ronds.

Pour déterminer la vitesse V_x de l'eau dans l'appareil on calcule la perte de charge pour une vitesse quelconque, soit par exemple *1m/s*.

La perte de charge comprend: le frottement dans le tube, supposé lisse, de 1 m 20 de long et de 52 mm de diamètre et la chute de pression à travers les clapets. Il a été supposé que chaque clapet du type employé peut-être assimilé à un clapet de retenue industriel. Un tel clapet peut être remplacé par une longueur fictive de tuyauterie égale à 6 m.

La longeur fictive entrant en ligne de compte pour le calcul de la perte de charge, dans les conditions supposées, comprend d'une part la longueur réelle soit 1 m 20, d'autre part, la longueur fictive remplaçant les 5 clapets: 30 m, soit au total: 31 m 20.

En prenant le nombre donné par la table de Prony, la perte de charge par mètre est de 24·4 mm de colonne d'eau, soit pour l'appareil 24·4. 31·20 = 760 mm.

Or nous avons vu plus haut que la pression dynamique n'était que de 200 mm. Les pertes de charge variant très sensiblement comme le carré de la vitesse, la vitesse varie comme la racine carré de la pression disponible. La vitesse réelle de l'eau dans l'appareil est donc : $\sqrt{\frac{200}{760}} \# 0{\cdot}5$ m/s.

En résumé la vitesse de l'eau dans le carottier est environ le quart de sa vitesse de descente; en d'autres termes, le prelèvement intéresse une colonne d'eau d'environ 5 m, réduite dans le rapport 1/4.*

On peut vérifier cette approximation théorique par l'expérience suivante: Après avoir rempli le carottier d'une matière colorante, il suffit de filmer en scaphandre autonome, sa descente pour se rendre compte des différences de niveaux nécessaires au complet renouvellement de l'eau dans celui-ci.

Cette expérience n'a pu être faite en raison de la perte de l'appareil. Cependant il nous restait un étage prototype, muni de deux clapets identiques à ceux qui entraient dans la construction du carottier. Cet étage, rempli de bleu de méthylène a été envoyé dans la mer dans les conditions habituelles et nous avons pu constater, en scaphandre autonome, que le renouvellement de l'eau était complet tous les trois mètres environ. Ces trois mètres correspondent donc à l'action de 2 clapets, le carottier perdu en ayant 5, le renouvellement de l'eau devait se faire en 8 m environ.

Cette approximation expérimentale est donc du même ordre de grandeur que l'approximation théorique.

Tout ceci laisse donc penser que le renouvellement de l'eau dans le carottier est complet dans les dix derniers mètres au-dessus du sédiment et par conséquent que les différences de teneur en oxygène observées dans les étages successifs du carottier correspondent bien à des différences réelles dans ces dix derniers mètres. Il est même possible qu'elles ne fassent que traduire, à une échelle réduite, des différences plus importantes qui existeraient au ras même du sédiment.

D'autre part, quand le carottier pénètre dans le sédiment, la carotte, comprimée à son entrée dans le tube, doit probablement libérer une faible quantité de l'eau dont elle est imbibée qui peut se mélanger à celle recueillie immédiatement au-dessus. Des expériences en cours préciseront ce point particulier.

* Il résulte de tout ceci que le rapport *vitesse de descente vitesse de l'eau dans le carottier* est une constante qui ne dépend que de la construction de l'appareil. En effet, d'une part la pression que nous appellerons motrice H, qui fait circuler l'eau dans le carottier est proportionnelle au carré de la vitesse de descente V, et d'autre part, la vitesse de circulation V_x dans le carottier est proportionnelle à la racine carré de cette pression H, soit en définitive à V.

Quoiqu'il en soit, nous pensons que ces observations peuvent avoir quelque intérêt en ce qui concerne l'évolution biologique des sédiments et aussi l'écoulement de l'eau sur le fond.

Il est intéressant de rappeler que le Dr. F. F. KOCZY* qui, au cours de la *Swedish Deep-sea Expedition* a fait, à bord de l'*Albatross*, des analyses d'eau prélevée par bouteilles échelonnées de 3 m à 500 au-dessus des grands fonds océaniques, a signalé brièvement une chute brusque de la teneur en silicate, en phosphate et aussi en oxygène, dans la couche d'eau de 20 à 50 m d'épaisseur, qui recouvre les sédiments, c'est-à-dire dans une zone de turbulence presque nulle. De telle sorte que le phènoméne étudié ici semble avoir un certain caractère de généralité que la publication des résultats annoncés précisera.

Le Dr. KOCZY estime, ainsi que nous en avions émis l'hypothèse pour l'oxygène, que ce sont les processus biologiques et chimiques ayant leur siège dans les sédiments ou à leur surface qui sont responsables de la consommation de ces éléments.

* (1950) *Die Naturwiss*, **37**, 360; (1951) *Assoc. Ocean. phys. Assemblée générale Bruxelles*, Proc. Verb. No. 5, 145.

Institut d'Oceanographic, Paris 5.

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Deep-Sea Research, 1954, Vol. 1, pp. 95 to 97. Pergamon Press Ltd., London.

Ueber Suesswasserdiatomeen in Atlantischen Tiefseesedimenten

Vorläufige Mitteilung

R. W. KOLBE

(*Received* 11*th November* 1953)

Summary—One of the most remarkable features of the deep-sea sediment cores collected by the Swedish Deep-Sea Expedition is the presence of fresh-water diatoms. Every level of the off-shore diatomiferous cores examined so far contained a considerable amount of fresh-water forms, chiefly *Melosira granulata* and *M. ambigua*. The frequency in some instances was more than 1,000 frustules per slide (max. 1,900 frustules per slide). One level contained fresh-water species only. Another interesting fact was the frequent occurrence of silicified epidermal cells belonging to *Cyperaceae* or *Gramineae*.

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IM Auftrage der schwedischen Tiefsee-Expedition werden die Diatomeen der Lotkerne, die diese Expedition im äquatorialen Atlantischen Ozean sammelte, vom Autor bearbeitet. Beim Durchmustern des reichen Materials macht man die Beobachtung, die sich als eine der auffallendsten—ja vielleicht die auffallendste—förmlich aufdrängt, dass ausgesprochen typische *Süsswasserdiatomeen* in allen diatomeenführenden Lotkernen und deren verschieden Horizonten konstant vorkommen. Einige Lotkerne, bezw. einige Schichten derselben, enthalten überhaupt keine Diatomeen; diese Lotkerne enthalten gewöhnlich auch keine Reste von Radiolarien und Silicoflagellaten. Ob der Ausfall der Kieselskelette dieser Organismen durch völlige Korrosion oder andere Umstände hervorgerufen wurde, mag hier dahingestellt sein. In allen anderen diatomeenführenden Lotkernen, bezw. Schichten, wiederholt sich stets das gleiche Bild: neben einer mehr oder minder reichen Auslese von marinen Planktondiatomeen, die natürlich numerisch dominieren, sind stets in verhältnismässig geringer und wechselnder Individuenzahl Süsswasserdiatomeen eingestreut. Das Auffallende ist jedenfalls die Konstanz ihres Auftretens.

Da der Befund von Süsswasserdiatomeen in weit vom Festland entfernten Tiefseesedimenten jedenfalls eine ungewöhnliche Erscheinung darstellt, lag es nahe, nach Fehlerquellen bei der Präparation des Materials zu suchen. Alle Glasgefässe und sonstiges Werkzeug wurden stets peinlich rein gehalten; im Uebrigen aber wurde das ganze Instrumentarium seit 3 Jahren ausschliesslich zur Präparation von Sedimenten aus dem äquatorialen Pazifik benutzt. Es konnte mithin überhaupt nicht mit Süsswassermaterial verunreinigt gewesen sein, denn in den Pazifik-Sedimenten wurden nie Süsswasserformen nachgewiesen. Schliesslich zeigen die überraschend hohen Frequenzzahlen für *Melosira granulata* (s. unten) dass von einer Verunreinigung oder einer zufälligen Fehlerquelle nicht die Rede sein kann.

Die Artliste der Süsswasserdiatomeen aus den atlantischen Tiefseesedimenten umfasst jetzt schon – vor Abschluss dar Untersuchung – die stattliche Anzahl von über 50 Formen. Diese Formen rekrutieren sich aus den verschiedensten ökologischen Gruppen: Plankton, Benthos, Arten eutropher (meist) bis dystropher Gewässer. In

weitaus den meisten Fällen sind die Formen in ein bis wenigen Exemplaren je Präparat einer angereicherten Sedimentauftragung vorhanden. Eine Ausnahme bildet *Melosira granulata* (Ehr.) Rlfs, die in allen diatomeenführenden Sedimenten des Gebiets konstant und häufig in einer grossen Individuenzahl (bis zu 1900 Exemplaren je Präparat) auftritt. LOHMAN (1941) war wahrscheinlich der Erste, der auf die Gegenwart dieser Form in einigen Grundproben des Nordatlantik nachdrücklicher hinweis. Die Form war selten und LOHMAN erklärt ihre Gegenwart entweder durch das Abschmelzen eines Eisbergs oder durch Transport aus einer Flussmündung. Die erste Erklärung scheint wenig wahrscheinlich; es ist kaum anzunehmen, dass diese Form typisch eutropher Gewässer sich in den Entstehungsgebieten der Eisberge stärker entwickeln kann.

Neben *Melosira granulata* (Ehr.) Rlfs sind noch *Melosira ambigua* (Grun.) O. Müll. und *Stephanodiscus astraea* (Ehr.) Grun. zu nennen, die häufiger, jedoch nie so häufig wie *Melosira granulata* auftreten.

Ausser den Süsswasserdiatomeen müssen noch typische Kieselreste erwähnt werden, die wegen ihres Ursprungs aus dem Süsswasser bezw. dem Festland interessant sind. Es sind dies die sogenannten " Kiesel-Kurzzellen " (vgl. GROB 1896 und PRAT 1935) der *Gramineen* und *Cyperaceen*. Es sind kurze Epidermiszellen, deren Lumen während des Lebens der Pflanze durch Kieselsäure ausgefüllt wird. Diese relativ kompakten Kieselkörper widerstehen ausgezeichnet der Korrosion und finden sich in den vorliegenden Sedimentprobem in recht grosser Häufigkeit und Konstanz (die Gebilde nehmen in Bezug auf deren Häufigkeit die zweite Stelle nach *Melosira granulata* ein). Sie sind, soweit man weiss, bisher nicht aus Tiefseesedimenten beschrieben worden, aber ihr Vorkommen in Süsswassersedimenten ist bekannt. Ihre Formen sind so charakteristisch, dass sie Kaum mit Kieselkörpern anderen Ursprungs zu verwechseln sind.

Es wurde anfangs erwähnt, dass die untersuchten Lotkerne weit vom Festlande entnommen wurden und dass daher die Gegenwart von Süsswasserformen bemerkenswert ist. Nachstehend sind einige sehr ungefähre Zahlen für diejenigen Lotkerne angeführt, welche sich durch besonderen Reichtum an Süsswasserformen auszeichnen :

		Entfernung von dem nachsten Küstenpunkt (in km):	
Lotkern No.	*Geogr. Lage*	*von Afrika*	*von Südamerika*
234	N 05° 45′ : W 21° 43′	870	1400
235	N 03° 12′ : W 20° 25′	1050	1800
238	S 00° 07′ : W 18° 12′	1160	1600

Es ist bezeichnend, dass die 3 häufigsten Süsswasserformen des vorliegenden Materials typische Kosmopoliten sind und eutrophe Gewässer bevorzugen, ohne aber auf sie angewiesen zu sein. *Melosira granulata* ist in eutrophen Flüssen der ganzen Welt ausserordentlich häufig; über *Melosira ambigua* schreibt HUSTEDT (1949), der die Diatomeen des im tropischen Afrika gelegenen belgischen Nationalparks untersuchte, sie sei " bei weitem die häufigste der pelagischen Arten des undersuchten Gebiets." Die Wahrscheinlichkeit, dass der Ursprung der Süsswasserformen der vorliegenden Tiefseesedimente in den grossen Strömen von Afrika und Südamerika zu suchen ist, dürfte schon aus ökologischen Gründen sehr gross sein.

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Zum Schluss sei noch eine sehr merkwürdige Beobachtung erwähnt. Im Lotkern 234 in einer Sediment-Tiefe von 552 cm wurde eine Schicht angetroffen, deren Diatomeenbestand sich *ausschliesslich* aus Süsswasserdiatomeen zusammensetzte (mit Ausnahme eines einzigen Fragments einer marinen Form). Wenn man die Probe durchmusterte, so hatte man den Eindruck, ein Süsswassersediment vor sich zu haben. Ausser der " obligaten " *Melosira granulata* konnten nicht weniger als 17 Süsswasserformen notiert werden. Diese eigenartige Schicht scheint nur eng begrenzt zu sein, denn der darüber liegende Horizont 471 cm wies die übliche Zusammensetzung (marine Formen und – selten – *Melosira granulata* sowie Kieselkurzzellen) auf, während der benachbarte tiefere Horizont 651 cm keine Diatomeen enthielt mit Ausnahme eines Fragments von – bezeichnenderweise – *Melosira granulata*.

Auf welche Weise bezw. unter welchen Umständen sich diese einzigartige Schicht bilden konnte, ist z.Zt. eine offene Frage.

Stockholm, Paläobotanische Abteilung des Reichsmuseums.

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Fig. 1. Map showing the distribution of samples and the localities investi

stigated. The figures refer to the sample numbers of Tables 1-10.

Deep-Sea Research, 1954, Vol. 1, pp. 98 to 120. Pergamon Press Ltd., London.

On the relative abundance of the stable carbon isotopes in marine sediments*

By Sture Landergren

Appendix : The Conversion of Organic Carbon to Carbon Dioxide and the Preparation of Barium Carbonate for Mass Spectrometric Determination.

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(*Received 5 November*, 1953)

ABSTRACT

The ratio $^{12}C/^{13}C$ has been determined in about 200 samples of marine sediments settled under different geological conditions. It is shown that differences in the water conditions prevailing during the formation of the sediments have affected the relative abundance of the stable carbon isotopes in the calcite. The isotope exchange in marine sediments is discussed.

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INTRODUCTION

The statement by A. O. Nier and E. A. Gulbransen (1939) that the ratio $^{12}C/^{13}C$ is higher in carbon derived from organic matter than in that from carbonate has been confirmed and discussed by several authors (K. Rankama (1948), F. E. Wickman and H. v. Ubisch (1951), Wickman, Blix, and v. Ubisch (1951), and H. Craig (1953)). As the accuracy of the mass spectrometric measurements increases even slight variations in the carbon isotope ratio can be discussed.

The scope of the present study is to ascertain whether or not variations in the isotope ratio can be set in relationship with differences in the milieus of deposition on the basis of the carbon dioxide cycle in the sea.

Clearly, when discussing the problem of the geological significance of the variations in the isotope ratio the research material must be selected so that differences in the geological milieus are evident or likely, and that the variations in the isotope ratio are known from a sufficient number of analyses. As far as possible the samples are selected with regard to this stipulation. The following material has been investigated :

1. Samples from two zones of Lower Ordovician (Arenig) : *Limbata* and *Planilimbata* Limestone from different Scandinavian localities.
2. Cambrian and Ordovician bituminous limestone from Swedish localities.
3. Limestone from Upper Ordovician (Ashgill) from a deep boring at File Haidar, Gotland, Sweden.
4. Deep-sea sediment from the Equatorial Atlantic and the Western Pacific.
5. Alum shale from a deep boring at Södra Sandby, Sweden.
6. *Dictyonema* Shale (Tremadoc) from different Scandinavian localities.

* Paper No. 7 in a series devoted to the application of isotope ratios to geological problems.

7. Shales from the Oslo region :
   a. *Phyllograptus* shale, etage 3 b (Arenig)
   b. *Ogygiocaris* shale, etage 4 a (Llandeilo)
   c. *Tretaspis* shale, etage 4 c (Caradoc).

The preparation of the samples to be analysed has been performed by A. PARWEL. The technique used for the preparation of carbonate carbon is described by WICKMAN, BLIX, and v. UBISCH (1951). The conversion of organic carbon to barium carbonate is described by A. PARWEL in an Appendix to this paper.

The mass spectrometric measurements were performed by Mr. R. RYHAGE at the Department of Chemistry of Karolinska Institutet, Stockholm. The reproducibility of the results is estimated to $\pm 0{\cdot}05$ units in most cases.

The localities are set out on the map in Fig. 1 and the figures refer to the sample numbers of Tables 1-10 where the analytical results are presented.

Table 1

Limbata Limestone

Abbreviations : r = red, reddish grey or brown coloured sediments ; g = grey, greyish green or black coloured sediments ; p = pyrite bearing.

No.	Locality	Colour	*12C 13C
	(a) Sweden		
1	Brunflo, Jämtland	r	88·60
2	SE Skattungsbyn, Dalarna	r	88·58
3	Biludden, Gävle	r	88·52
4	Erken, Uppland	r	88·52
5	Borghamn, Östergötland	r	88·52
6	Borghamn, ,,	r	88·58
7	Toknäshamn, Öland	r	88·53
8	Rödstensudden, ,,	r	88·61
9	Borgholm, ,,	r	88·67
10	Mörbylånga, ,,	r	88·53
11	Ottenby, ,,	g	88·65
12	Lanna, Närke	r	88·43
13	Lanna, ,,	r	88·44
14	Lanna, ,,	r	88·58
15	Lanna, ,,	g	88·58
16	Lanna, ,,	g	88·64
17	Lanna, ,,	g	88·65
18	Lanna, ,,	g	88·72
19	Lanna, ,,	g	88·79
20	Yxhult, ,,	g	88·73
21	Holmstorp, Tysslinge ,,	g	88·69
22	Ödegarden, Tidaholm, Västergötland	g	88·78
23	W Flittorp, Tiarp, Tidaholm, ,,	g	88·85
24	Tomtens kalkbrott, Tidaholm, ,,	g	88·55
25	Smedsgården, Tidaholm, ,,	g	88·85
26	Lilla Stolan, N Billingen, ,,	gp	88·80
27	Karlsfors, Billingen, ,,	g	88·70
28	Hällekis kalkstensbrott, Kinnekulle, ,,	r	88·63
29	Gössäter, Kinnekulle, ,,	r	88·59
30	Killeröd, Skåne	g	88·64
	(b) Other Countries		
31	Mäeküla, Esthonia	g	88·69
32	Vekkeröy, Norway	g	88·80
33	Hemmensborg, Oslo, Norway	g	89·18

* The Stockholm standard is $\delta = -10{\cdot}71$ on the Chicago scale, according to the calibration kindly performed by Dr. H. CRAIG. Conversely, the Chicago standard is 88·51 on the Stockholm scale.

THE *LIMBATA* LIMESTONE

Most samples emanate from the Geological Survey of Sweden and were selected under the guidance of Professor P. THORSLUND, Uppsala, one time director of the Museum of the Survey. Some samples were placed at my disposal by Mr. T. TJERNVIK at the Palaeontological Department of the University of Uppsala. The samples from Norway and Esthonia emanate from the Palaeozoological Department of the Museum of Natural History, Stockholm, and were placed at my disposal by Dr. T. ÖRVIK and Mr. H. MUTVEI.

As seen from Table 1 the ratio varies between 88·43 and 89·18. The magnitude of this variation cannot solely be accounted for by errors in the mass spectrometric measurements. The variations may have a real sense.

A closer examination of the results shows that the variations in the isotope ratio is in relation partly to the colour of the samples and partly to the localities of the samples.

As to the colour of samples a brief microscopical and spectrochemical investigation indicates that the red-coloured samples are as fossiliferous as the non-red ones. The total amount of iron is about the same, indicating that the difference in colour is due to the iron oxides in the red limestone being in a higher oxidation state than in the non-red ones. The latter were obviously formed under reducing conditions, or have undergone a secondary reduction. With regard to the oxidation state the samples are divided into " red " and " grey " (including slight variations in colour as mentioned in the abbreviations of Table 1).

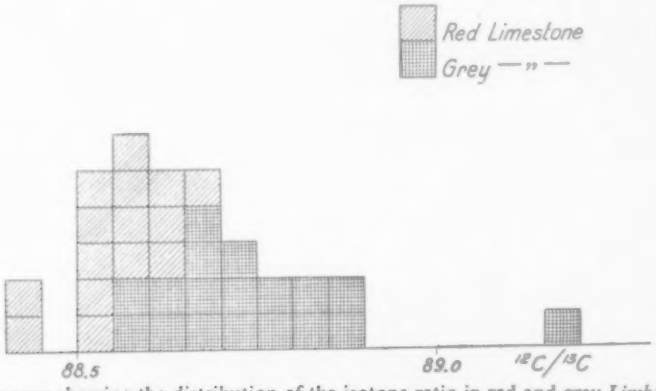

Fig. 2. Histogram showing the distribution of the isotope ratio in red and grey *Limbata* limestone. Each square = one analysis.

The relationship between the magnitude of the ratio and the oxidation state of the samples is illustrated in the histogram in Fig. 2 where each square represents one analysis and the abscissa is the ratio. As seen from the histogram the red-coloured samples tend to lower values and the grey ones to higher values.

The cause of the difference in the oxidation state of limestones has given rise to lively discussions in the literature, and opinions diverge largely. It is not my intention to enter into this intricate problem. Only the relationship stated between the oxidation state and the magnitude of the ratio will be discussed, with special regard to the *Limbata* Limestone.

It is unlikely that there is any direct relationship between the oxidation state of a sediment and the magnitude of the ratio. There seems to be a geological factor at work, affecting both the oxidation state and the relative abundance of the stable carbon isotopes in the settled carbonate thus giving rise to the relationship mentioned.

A presupposed relationship between the relative abundance of the isotopes and the localities of the samples implies, of course, a relationship between the ratio in question and the geological conditions prevailing during the precipitation of calcite in the different parts of the "*Limbata* Sea" within this region. However, our present knowledge of the extent and boundaries of the *Limbata* Basin is very scanty, due mainly to the few remnants of Cambro-Silurian sediments within the Scandinavian region, so that only some general viewpoints concerning the probable cause of this relationship can be adduced.

There are reasons for believing that the *Limbata* Limestone was formed in a comparatively shallow basin with its deepest part towards S.W. (Närke, Västergötland) and W. (the Oslo region). In the eastern part *Limbata* Limestone occurs on the Isle of Öland but is absent on the Isle of Gotland in the Baltic Sea. Whether Gotland at that time was terrestrial or not is still open to question. Anyhow, the occurrence of *Limbata* Limestone in Esthonia indicates that there probably existed a communication with the Silurian sea that covered Central Russia (cf. H. TERMIER and G. TERMIER (1952) and N. S. SCHATSKY (1952)).

On regarding the distribution of red and grey limestone within the region in question one finds that the grey limestone is most frequent in the south-western and western parts. The red limestone on the other hand, is most abundant towards the north-eastern and eastern parts, possibly representing shallower areas of the *Limbata* Basin. Now the question might arise how these occurrences can be connected with the conditions during the precipitation of calcite on the one hand and the magnitude of the ratio on the other.

A reducing milieu generally prevails in comparatively stagnant and poorly aerated water where the decomposition of organic matter occurs. It is reasonable to assume that such conditions develop in the deepest parts of a basin. Oxidized limestone, on the other hand, is formed in such parts of the basin where circulating and oxygenated water is acting, viz. in the more shallow parts and probably also near the shores.

Tentatively the relationship between the magnitude of the isotope ratio and the oxidation state of the sediments may be looked upon from this point of view. In stagnant water where organic processes are acting the carbon dioxide cycle – a link of which is the precipitation of calcite – is affected by the addition of carbon dioxide derived from organic matter enriched in the light isotope, provided that the exchange: Carbon dioxide $\rightleftarrows$ bicarbonate $\rightleftarrows$ carbonate, is part of the local carbon dioxide cycle developed in the system : bottom water – precipitate. If the contribution of organic carbon dioxide, involved in the exchange : Carbonate-bicarbonate, exceeds that of carbon dioxide derived from the superposed water (from the system : sea water – air) an increase in the light isotope in the precipitated calcite will occur. The magnitude of the ratio is obviously also dependent on the local conditions and the rate of the exchange : carbonate-bicarbonate.

The oxidized sediments were probably settled under different conditions. The water was non-stagnant and oxygenated. It is likely that such conditions generally prevail in the shallower parts of the basin, viz. near the shore. No local carbon

dioxide cycle can develop under such conditions. The isotope ratio in the precipitated calcite will approach that of marine limestones in general, where the isotope exchange tends to an equilibrium value significant for marine conditions.

In order to obtain further support for the hypothesis that the oxidized limestone in this case was settled in the near shore parts of the *Limbata* Basin I have determined the content of boron in about 20 samples of the *Limbata* Limestone of different oxidation states. According to an investigation of the geochemistry of boron (LANDERGREN, 1945) the amount of this element in the hydrolysate component of a sediment is symbatic with the salinity of the water of the surroundings. Thus, the ratio B/Al increases with increasing salinity. The results of this study are illustrated

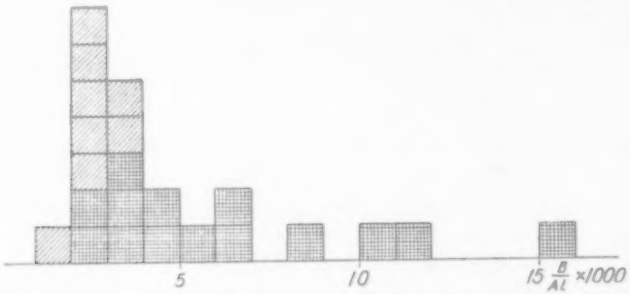

Fig. 3. Histogram showing the distribution ratio B/Al in red and grey *Limbata* Limestone.

in the diagram of Fig. 3 where the abscissa represents the ratio B/Alx1000. Each square is one analysis. As seen from the diagram the oxidized limestones have a lower B/Al ratio than have the reduced ones. This indicates that the red sediments were settled in water with lower salinity than was the case for the reduced sediments deposited. It is likely that an influx of fresh water to the basin, thus decreasing the salinity, is a phenomenon more significant for near shore than off shore parts. This result is in agreement with the concept based on the ratio as mentioned above.

In this connection it ought to be mentioned that some authors, i. a. G. KAUTSKY (1949), have attempted to relate the red-coloured Cambro-Silurian limestone to intervals of non-sedimentation, mainly due to periodic fluctuations in the water level, so that parts of these sediments periodically became terrestrial and subjected to aerial weathering. These parts are red-coloured. In any case, the low figures of the isotope ratio in the red *Limbata* Limestone do not contradict such an hypothesis.

Evidently the water conditions in a shallow basin could become very irregular due to many factors : bottom currents, bottom topography, fluctuations in the water level, etc. affecting the ratio in the sediments. A reducing milieu, for example, may also occur in relatively shallow parts of a basin with restricted communication with open water, and some of the red sediments may have been subjected to a secondary reduction. In fact, some of the figures of the isotope ratio deviating from the general tendency, may be looked upon from this viewpoint.

THE *PLANILIMBATA* LIMESTONE

The isotope ratio has been determined in some few samples of *Planilimbata* Limestone. The *Planilimbata* Zone occurs close beneath the *Limbata* Zone, both from

Lower Ordovician (Arenig). Two samples are taken close to the limit of the *Limbata* Limestone. The samples were placed at my disposal by Mr. T. TJERNVIK, Uppsala. The analytical results together with some remarks on the stratigraphy of samples are presented in Table 2.

Table 2

Planilimbata Limestone

Abbreviations : See Table 1

No.	Locality	Colour	$^{12}C/^{13}C$	Remarks
34	Brännön, Sundsvall	r	88·58	Either from the lowest *Planilimbata* Zone or close below. At the primary transgression over Pre-Cambrian.
35	Holen, Orsa, Dalarna	r	88·78	Containing fragments of Pre-Cambrian. Immediately above a glauconite bearing clay, 30 cm over Pre-Cambrian, initiating the Cambro-Silurian.
36	Holen, Orsa, ,,	g	88·78	15 cm above sample No. 35.
37	Lanna, Närke	g	88·66	Comparatively coarse grained glauconite bearing, 95-100 cm above the limit to Cambrian.
38	Lanna, ,,	g	88·50	75-77 cm above the limit to Cambrian.
39	Yxhult, ,,	r	88·63	Close below the limit to the *Limbata* Limestone represented in sample No. 20, Table 1.
40	Borghamn, Östergötland	r	88·57	Close below the limit to the *Limbata* Limestone represented in sample No. 6, Table 1.

It is of interest to note that sample 34 emanates from one of the northernmost localities investigated. The sediment is red-coloured and regarded as having settled during the first transgression which covered the Pre-Cambrian of this region (personal communication from Mr. T. TJERNVIK). The isotope ratio is low which might be expected with regard to the water conditions during the precipitation of calcite as discussed before.

Samples 35 and 36 derive from a locality where glauconite occurs. They were taken in the immediate vicinity of a glauconite-bearing clay. Sample 35 is reddish grey and 36 is grey. The isotope ratio indicates that the sediments were settled in comparatively quiet water. The appearence of glauconite does not contradict such a concept.

The change in the isotope ratio in samples 37 and 38 is remarkable. The samples emanate from the same locality, no. 37 taken 95-100 cm and no. 38 75-77 cm above the limit of the Cambrian layers. The former sample is glauconite bearing, the latter contains no glauconite. The difference in the isotope ratio is notable, the glauconite bearing sample being relatively enriched in the light isotope (cf. samples 35 and 36). The comparatively low value of the isotope ratio in sample 38 may indicate that this limestone was settled under conditions preventing the development of a local carbon dioxide cycle. The conditions seem to have changed relatively rapidly since sample 37, taken only 20 cm above, is enriched in the lighter isotope.

Sample 39 is taken close below the limit of the *Limbata* Limestone from the same locality (cf. sample 20, Table 1). The red coloured *Planilimbata* Limestone has a

lower isotope ratio than has the overlayered grey *Limbata* Limestone. Also in this case there was a change in the water conditions from the preciptation of the *Planilimbata* Limestone and to that of the Limbata sediment.

Sample 40 is taken close below the limit of the Limbata limestone analysed (sample 6, Table 1). The ratios in the two samples are almost equal, indicating that no difference in the water conditions during their deposition occurred at this locality (Östergötland).

Judging from the samples of *Planilimbata* Limestone there seems to be no decided difference in the water conditions during the deposition of the limestones from the two adjacent zones.

BITUMINOUS LIMESTONE

Some few samples of Andrarum limestone (Middle Cambrian) and of bituminous limestone (Middle and Upper Cambrian and Lower Ordovicium) from different localities have been investigated. The isotope ratios have been determined both in the carbonate (samples 41-47) and in the organic carbon (samples 41-44). The samples emanate from the Palaeozoological Department of the Swedish Museum of Natural History, Stockholm and the University of Uppsala respectively. They were placed at my disposal by Messrs. Mutvei and Örvik, Stockholm, and T. Tjernvik, Uppsala. The results are presented in Table 3.

Table 3

Bituminous Limestone

No.	*Samples*	*Locality*	*Age*	$^{12}C/^{13}C$ Organic *carbon*	$^{12}C/^{13}C$ Carbonate *carbon*
41	Andrarum Limestone *Solenopleura*	Andrarum, Skäne	Middle Cambrian	90·93	88·96
42	"*Lepertitia*" primordialis *Lines* (?), *Agnostus laevigulata* zone	Gössäter, Kinnekulle, Västergötland	Middle Cambrian	91·14	88·98
43	Fossiliferous bituminous limestone, Peltura zone	Kinnekulle, Västergötland	Upper Cambrian	91·12	88·67
44	Bituminous limestone *Agnostus pisiformis*	Räbäck, Kinnekulle, Västergötland	Upper Cambrian	89·45	88·88
45	Conglomeratic bituminous limestone with *Parabolina spinulosa* and *Orucia lenticularis*	Gymninge, Närke	Upper Cambrian	—	88·81
46	Glauconite bearing limestone, 3-5 cms above the limit to Cambrian	Gymninge, Närke	Lower Ordovician	—	88·72
47	Grey clayish limestone, fossiliferous, zone of *Asaphus expansus*	Lanna, Närke	Lower Ordovician	—	88·69

The bituminous limestone has a special interest in connection with the black shales, especially the alum shale. In these sediments the calcite component is but sparingly abundant, occurring as minute fissures or veins. However, this calcite should not be confused with the bituminous limestone – in Sweden called "orsten" – occurring

as small lenses or concretions in the alum shale. There is a marked difference in the isotope ratio between the two calcite components mentioned which will be discussed in detail in connection with the black shales in a subsequent section.

The calcite carbon in the Andrarum Limestone and in that of the bituminous limestone show a slight enrichment in the light isotope compared with the *Limbata* and *Planilimbata* Limestones.

The isotope ratio in the organic carbon (samples 41-43) varies markedly for reasons plain enough if we bear in mind that the source material may be of various kinds.

ORDOVICIAN LIMESTONE FROM A BORE PROFILE AT FILE HAIDAR, GOTLAND

The samples hitherto discussed emanate from different localities scattered over the whole area investigated. It may be of interest, also to gain knowledge of the vertical distribution of the isotope ratio in a profile of limestone from a single locality.

Samples 48-98 emanate from a bore profile from a deep boring through Cambro-Silurian sediments at File Haidar on the Isle of Gotland in the Baltic Sea. The part

Table 4

Ordovician Limestone from the Deep Boring at File Haidar, Gotland

No.	Level (m)	$^{12}C/^{13}C$	No.	Level (m)	$^{12}C/^{13}C$
48	269·8	88·52	73	267·75	88·67
49	270·2	88·64	74	277·1	88·58
50	270·3	88·64	75	277·45	88·57
51	270·6	88·58	76	277·5	88·65
52	270·8	88·52	77	277·65	88·30
53	270·9	88·58	78	277·9	88·54
54	271·4	88·57	79	278·15	88·24
55	271·65	88·49	80	278·35	88·60
56	271·7	88·48	81	278·5	88·35
57	271·9	88·57	82	278·6	88·52
58	272·1	88·50	83	278·9	88·49
59	272·3	88·54	84	279·15	88·48
60	272·5	88·42	85	279·35	88·62
61	272·7	88·52	86	279·5	88·56
62	272·85	88·49	87	281·2	88·44
63	273·2	88·44	88	281·3	88·51
64	273·2(*)	88·48	89	281·65	88·48
65	273·44	88·54	90	281·75	88·59
66	273·85	88·49	91	282·0	88·56
67	274·15	88·52	92	283·45	88·60
68	275·7	88·38	93	283·7	88·50
69	276·1	88·49	94	284·2	88·49
70	276·3	88·59	95	285·1	88·37
71	276·5	88·60	96	288·0	88·47
72	276·55	88·57	97	288·65	88·56
			98	289·0	88·48

* Inclusion of calcite crystals.

of the core here studied is an algal limestone – in Sweden called the " Östersjökalk " – of Upper Ordovician, corresponding to Ashgill. A preliminary description of the stratigraphy and lithological character of the core is given by P. THORSLUND (1938)*. A brief summary of the geology, according to the author mentioned may be given.

* See THORSLUND and WESTERGÅRD (1938) where THORSLUND is responsible for the description of the silurian layers.

Samples 48-52 (269·8-270·8 m level) is the lowest part of a section of limestone described as a dark grey, slightly bituminous limestone, finely crystalline with irregular intercalations of darkish marly shales. The limestone is made up of irregularly limited layers, lenses, and occasional nodules.

Samples 53-67 (270·8-274·3 m) : light grey reddish limestone partly finely crystalline and partly almost compact.

Samples 68-95 (274·3-288 m) : Beds of the same general type as met with in the underlying part. The intercalated shaly layers, however, are slightly thicker and more separated from each other.

Samples 96-98 (288-289 m), finally, consist of grey and dark grey limestone, finely crystalline or almost compact and irregularly traversed by thin layers of dark marly shales, partly silicified.

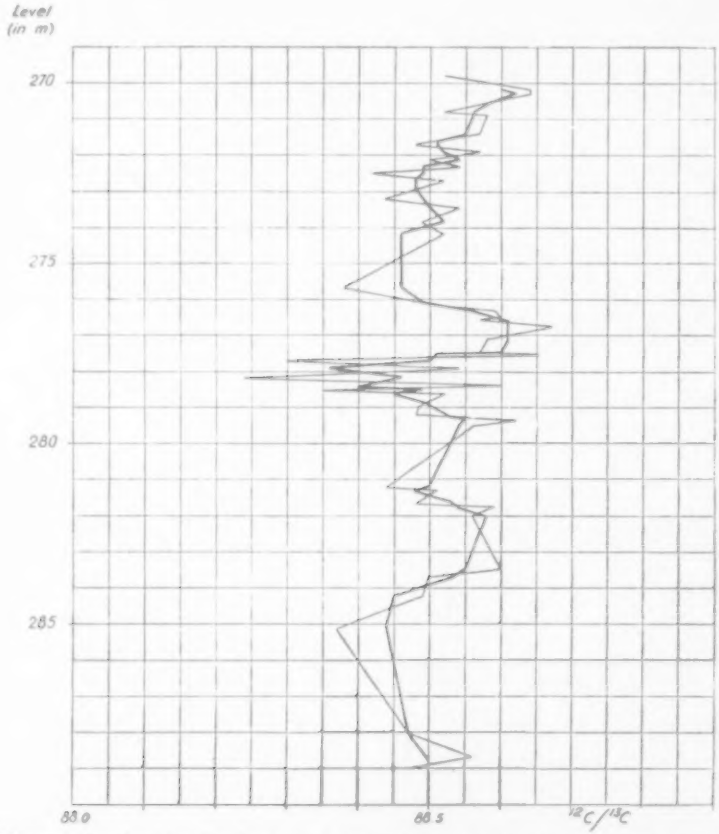

Fig. 4. Diagram showing the distribution of the isotope ratio in the bore profile at File Haidar, Isle of Gotland. The thin line represents the $^{12}C/^{13}C$ ratio determined. The heavy line represents the sliding average of three analyses.

As seen from Table 4, where the analytical results are set out, there are slight variations in the isotope ratio throughout the profile. The dispersion range of the ratio is 88·24-88·67 and the arithmetic mean is 88·52. Judging from the geological

features this limestone was probably deposited in an open marine milieu under slightly varying water conditions.

The variations in the isotope ratio are best illustrated in a diagram (Fig. 4). The abscissa is $^{12}C/^{13}C$ and the ordinate the level of the sample analysed. The thin line connects the analyses and the heavy line is the sliding average of three analyses.

Also in this case we have to reckon with the fact that variations in the isotope ratio have a real sense. The cause may be variations in the water conditions in the milieu of sedimentation. If such a relationship is presumed it is nevertheless very hard to find the fundamental cause. In the case of the *Limbata* Limestone the difference in the oxidation state of the limestone and the position of the localities of the samples could give information as to the reason for the relationship in question. In this case such indications are missing. Only some features in the lithological character of the sediment may give information if looked upon in connection with the geological evolution during the sedimentation of the layers here dealt with.

According to THORSLUND (1938) corrosion surfaces occurring in the sediment core are evidently formed during intervals of non-sedimentation and in addition during changes in sea level (cf. KAUTSKY, 1949). These interruptions in the sedimentation are regarded as being of short though varying duration. Such corrosion surfaces are discovered in the core although not in the part investigated as yet. Changes in the lithological character – as mentioned above – indicate nevertheless that there may have occurred changes in the water conditions during the settling of calcite which may be accounted for by the variations in the isotope ratio.

THORSLUND (1938) and KAUTSKY (1949) suggest that we have to reckon with two land elevations of importance within the Scandinavian region during Middle and Upper Ordovician. One is the so-called Ekne-elevation (Caradoc) and the other the Vojtja-elevation (Ashgill). Both these tectonic events are traced through the discovery of conglomerate horizons or interruptions in the sedimentation at several Scandinavian localities. On the Isle of Gotland these events are registered by periods of non-sedimentation, one below the portion of the core analysed, corresponding with the Ekne-elevation, and one above, corresponding with the Vojtja-elevation. Kautsky has further suggested that three minor elevations occurred during the settling of the algal limestone at File Haidar.

Ordovician is an epoch of revolution and in the light of the tectonic events mentioned it seems likely that they have influenced the conditions of the water where the calcite was deposited. If we employ a similar hypothesis as suggested in the section on the *Limbata* Limestone the changes in the water conditions may at least have contributed to the variations in the isotope ratio of the limestone as illustrated in the diagram (Fig. 4). In addition, there is a tendency to periodicity in the variations which may syncronize with the aforementioned tectonic events which are regarded as the primary cause of the changes in the water level in the Baltic Sea.

THE DEEP-SEA SEDIMENTS

During the Swedish Deep-Sea Expedition in 1947-1948 a large number of important core samples of deep-sea sediments were collected from different parts of the oceans. Thanks to the courtesy of Professor HANS PETTERSSON, leader of the expedition, samples of cores from the Atlantic and Pacific were placed at my disposal for studies on the carbon isotopes. Clearly, only minute quantities of the samples were available

and but few determinations have been carried out. Mass spectrometric determinations of the ratio were performed in samples partly from a long core from the Equatorial Atlantic and partly from eight cores of red clay from the Western Pacific. The amount of calcite in the red clay was so very small that it was necessary to join samples from different levels of the cores and in some cases also from different cores in order to obtain a quantity of calcite sufficient for the determinations.

THE SEDIMENT FROM THE ATLANTIC

The samples derive from a core taken from the " Romanche " deep gravel. Its position is : Lat. S 00°07′, Long. W 18°12′. Depth : 7315 m. Length of the core was 14·12 m.

The results are set out in Table 5. There is but little variation in the isotope ratio (88·67-88·80), as seen from the Table. The average is 88·74.

Table 5

Deep Sea Sediment from the Atlantic Ocean.

(From a core taken during the Swedish Deep Sea Expedition 1947-1948)
Lat. S 00°07′, Long W 18°12′.

No.	Cms from the top of the core	$^{12}C/^{13}C$
99	460·0- 461·5	88·67
100	580·0- 581·5	88·74
101	660·0- 661·5	88·75
102	819·5- 821·0	88·72
103	1050·0-1051·5	88·80
104	1140·0-1141·5	88·79
105	1310·0-1311·5	88·74

The calcite in the sediment derives mainly from shells of forminifera and the amount increases towards the deeper levels (LANDERGREN, 1954). The water conditions near the bottom is almost stagnant and only thermal convection occurs, as asserted by F. KOCZY (1953). The average of the isotope ratio is the same as that of the reduced Limbata limestone (see Table 10). Both sediments were settled under quiet water conditions with some organically derived carbon taking part in the local carbon dioxide cycle in milieus where carbonate carbon predominates.

THE RED CLAY FROM THE WESTERN PACIFIC

In the sediment from the Atlantic the amount of carbonate carbon is large compared with the amount of organically derived carbon. In the red clay, on the other hand, the proportion inorganic carbon/organic carbon is small. In fact, the amount of calcite carbon was in most cases below the limit for mass spectrometric determination. However, in a few samples it was possible to determine the isotope ratio both in the organic component and in the calcite so that the isotope exchange ratio could be calculated. The analytical results, the number of the cores, their position and the level from which the samples emanate are set out in Table 6.

The isotope ratio in the organic carbon is rather constant, indicating that the source material might be very similar. The ratio in the carbonate carbon has increased

by about one unit compared with the sediments hitherto discussed. One exception should be noted, however. In sample 107, Table 6 the ratio is 88·56, significant for a normal marine calcite. This sample, however, consists almost entirely of calcite from a near shore part of the Pacific (north of the Society Islands).

Table 6

Deep-Sea Sediment from the Pacific Ocean.

No.	*Core*	*Position :* *Lat.*	*Long*	*Cms from top*	$^{12}C/^{13}C$ in *Organic carbon*	*Carbonate carbon*
106	69	S 13°25′	W149°30′	30- 31·5	—	89·13
107	69			518·5- 520	—	88·56
108	70	S 11°15′	W150°30′	250·0- 251·5	90·39	89·76
109	70			270·0- 271·5	90·58	89·75
110	71	S 07°38′	W152°53′	290·0- 291·5	90·27	89·31
111	71			750·0- 751·5		
112	72	S 07°38′	W152°53′	1350·0-1351·5	90·62	—
113	72, 73	S 04°04′	W152°53′	—	90·27	—
114	73, 77	N09°30′	W148°40′	—	90·74	—
115	77, 83	N08°40′	W169°28′	—	90·70	—
116	83			260·0- 261·5	—	—
117	85	N05°34′	W172°12′	600·0- 601·5	—	—
118	85			1030·0-1031	90·38	—

According to F. KOCZY (personal communication) the red clay has settled under extremely quiet water conditions. Such conditions would consequently be favourable for the development of a minor carbon dioxide cycle : bottom water $\rightleftarrows$ precipitate where organically derived carbon involved in the cycle is in excess. The considerable increase in the isotope ratio is in good agreement with this assumption.

The isotope ratio in the deep sea sediment studied is of interest in so far that the ratio is strongly affected by the proportion of carbonate carbon/organic carbon in the milieu of deposition. This feature will be further demonstrated in the following section, where hydrolysates with a considerable amount of organic carbon and a low content of calcite will be discussed.

ALUM SHALE FROM A BORE PROFILE AT SÖDRA SANDBY, SOUTHERN SWEDEN

A boring through the alum shale about 90 m deep has been made. At about 90 m the boring was interrupted due to the appearance of a diabase. The lithological and stratigraphical character of the core is described by A. H. WESTERGÅRD (1944), and the reader is referred to his paper for details.

Stratigraphically the core is subdivided into three zones as follows :

Zone	Age	Thickness (in m.)
Dictyonema shale	Lower Ordovician	9·6
Olenidian shale	Upper Cambrian	55·8
Paradoxides shale	Middle Cambrian	24·1
	Total thickness :	89·5

Chemical analyses and the determination of some physical properties were performed by Dr. G. ASSARSSON (1944). On the basis of ASSARSSON's results Dr. J. EKLUND kindly calculated the average contents of organic and carbonate carbon in the core. These estimates are given below.

	per cent
Organic carbon derived from the alum shale	5·5
Organic carbon from bituminous limestone	0·7
Calcite carbon from bedded limestone	0·1
Calcite carbon from calcite disseminated in the alum shale	0·2

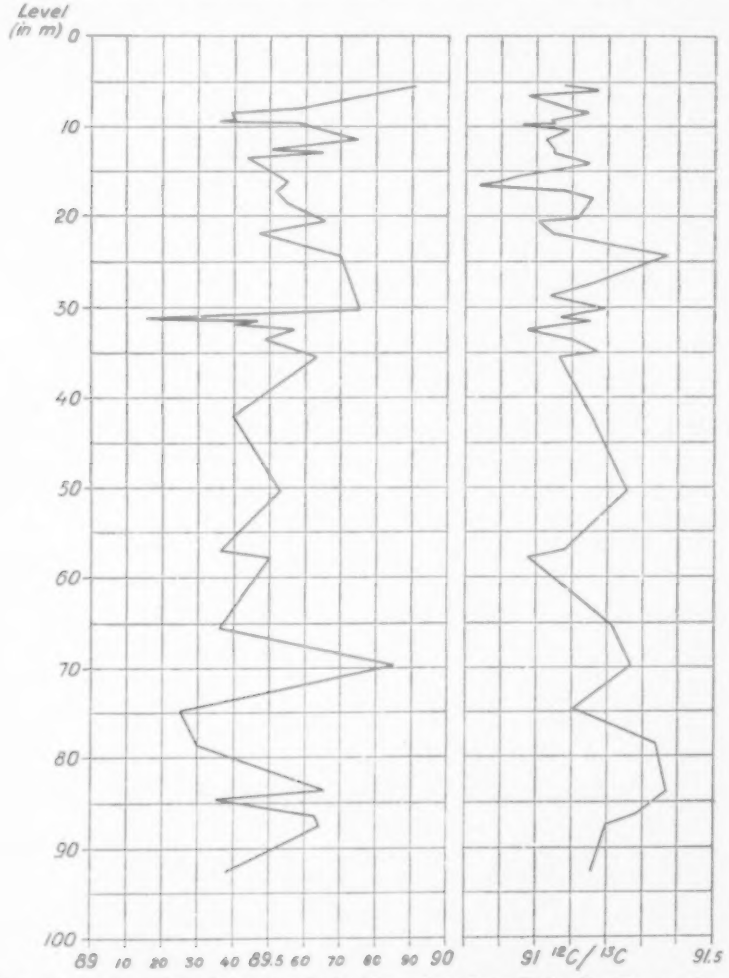

Fig. 5. The distribution of the isotope ratio in Alum shale from Södra Sandby, southern Sweden. The left-hand diagram is the isotope ratio in the carbonate component and the right-hand diagram that of organic carbon.

These figures show that the ratio organic carbon/carbonate carbon is about 20, i.e. the content of organic carbon predominates.

Most geologists agree that the alum shale was deposited under very tranquil

water conditions in a reducing milieu where the pH conditions prevented the precipitation of calcite on a large scale. According to an investigation by F. LEUTWEIN (1951) on the geochemistry of alum shale from Thüringen, Germany, the formation

Table 7

Alum Shale from a Bore Profile at Södra Sandby, Skåne

No.	Level (m)	$^{12}C/^{13}C$ in Organic Carbon :	$^{12}C/^{13}C$ in Calcite Carbon :	K1 :	Stratigraphic Remarks
119	5·28- 5·78	91·08	89·91	1·013	
120	5·78- 6·15	91·17	—	—	
121	6·30- 7·04	90·98	—	—	
122	7·68- 8·30	91·09	89·58	1·017	
123	8·30- 8·80	91·14	89·39	1·019	
124	8·80- 9·28	91·04	89·40	1·018	
125	9·28- 9·63	91·05	89·36	1·019	*Dictyonema flabelliforme*
126	9·63- 9·94	90·97	89·58	1·015	
127	9·94-10·15	91·09	—	—	— Bituminous limestone
128	11·06-11·66	91·03	89·74	1·014	
129	12·33-12·80	91·05	89·51	1·017	
130	12·80-13·16	91·05	89·64	1·016	
131	13·16-13·81	91·10	89·43	1·019	
132	13·81-14·26	91·14	—	—	— Bituminous limestone
133	15·12-15·72	90·96	—	—	
134	15·72-16·42	90·89	89·55	1·015	
135	16·42-16·98	90·84	89·54	1·015	
136	16·98-17·30	91·08	89·52	1·017	
137	17·79-18·30	91·16	89·55	1·018	
138	19·84-20·40	91·12	—	—	— Bituminous limestone
139	20·40-20·90	91·01	89·66	1·015	
140	21·80-22·24	91·05	89·47	1·018	
141	24·21-24·70	91·37	89·70	1·018	
142	27·20-27·76	91·14	—	—	
143	28·68-29·25	91·04	—	—	
144	29·71-30·44	91·19	89·76	1·016	
145	30·72-31·35	91·07	89·16	1·021	
146	31·35-31·75	91·16	89·47	1·019	— Bituminous limestone
147	31·75-32·15	91·05	89·41	1·018	*Peltura scarabaeoides*
148	32·15-32·65	90·98	89·57	1·016	
149	33·30-33·86	91·11	89·49	1·018	
150	34·70-35·20	91·17	—	—	— Bituminous limestone
151	35·20-35·70	91·07	89·66	1·016	
152	41·60-42·20	91·16	89·40	1·020	— Bituminous limestone
153	50·00-50·50	91·26	89·53	1·019	
154	56·70-57·30	91·08	89·37	1·019	*Homognostus obesus*
155	57·65-58·00	90·98	89·50	1·017	— Bituminous limestone
156	65·00-65·50	91·22	89·36	1·021	
157	69·50-70·00	91·27	89·85	1·016	
158	74·50-75·00	91·11	89·25	1·021	— Bedded (Andrarum) limestone
159	78·45-79·00	91·33	89·30	1·023	*Triplagnostus lundgreni*
160	83·50-84·10	91·37	89·66	1·019	— Bituminous limestone
161	84·47-85·00	91·34	89·36	1·022	*Ptychagnostus punctuosus*
162	86·00-86·65	91·28	89·63	1·018	
163	86·88-88·00	91·20	89·64	1·017	
164	92·00-93·30	91·16	89·38	1·020	— Bituminous limestone
					Diabase

of this sediment is to be compared with that of sapropel and ooze. The geochemical features mentioned are evidently favourable for the development of a local carbon dioxide cycle within the bottom layer of the basin where the alum shale was deposited, and where the contribution of organically derived carbon predominates. The analytical results support this supposition.

The isotope ratio of organic carbon was determined in 46 samples and of calcite carbon in 39. The results are set out in Table 7 where also the isotope exchange ratios ($'K$), the levels from which the samples emanate, and some stratigraphic remarks are found. In Fig. 5 the variations in the ratios of organic and inorganic carbon respectively are illustrated. In table 10 and Fig. 6 the average and range of dispersion of the isotope ratio in the alum shale can be compared with that of other sediments investigated. Samples 123-128 derive from the *Dictyonema* Zone and will be discussed in the next section.

The variations in the isotope ratio in both the organic and carbonate carbon may be due to slight variations in the water conditions during the deposition of alum shale. However, the cause of the considerable enrichment in the light isotope of the calcite component is evidently dependent on the isotopic composition of the carbon dioxide taking part in the exchange $CO_2 \rightleftarrows CO_3^{2-}$ in the system: bottom water – precipitate. This carbon dioxide derives partly from organic matter undergoing decomposition. The contribution of carbon from the surface region in cummunication with the system : sea water – atmosphere derives partly from dead shell-bearing organisms sinking to the bottom region and partly from carbon dioxide from the surface water, but this contribution is restricted. In such a milieu where organically derived carbon is enriched the isotope ratio of calcite precipitated is in isotope exchange with carbon dioxide of the local milieu. The isotope exchange will be discussed in a later section.

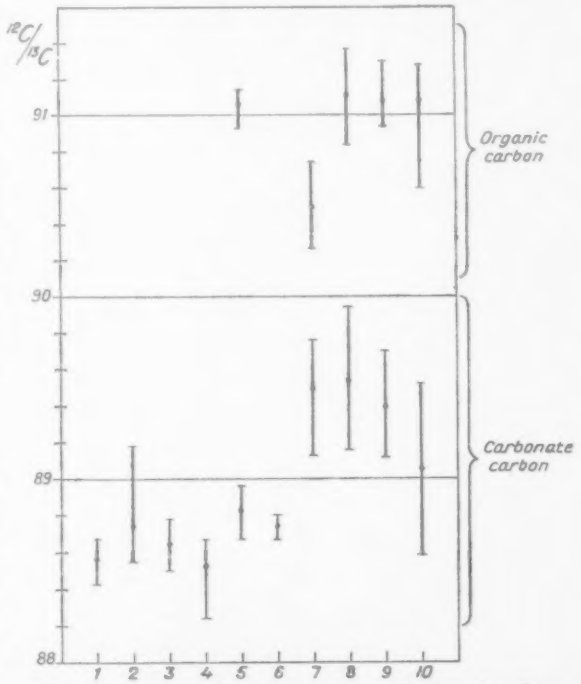

Fig. 6. Diagrams showing the range of dispersion (heavy lines) and the average figures (dots) of the $^{12}C/^{13}C$ ratio. 1. Oxidized *Limbata* Limestone. 2. Reduced *Limbata* Limestone. 3. *Planilimbata* Limestone. 4. Ordovician limestone from File Haidar, Isle of Gotland. 5. Bituminous limestone. 6. Deep sea sediment from Central Atlantic. 7. Red clay from Western Pacific. 8. Alum shale from Södra Sandby, southern Sweden. 9. *Dictyonema* Shale. 10. Sundry shales from the Oslo region.

THE *DICTYONEMA* SHALE

Samples 123-128 of the alum shale from Södra Sandby (Table 7) belong to the *Dictyonema* Zone of Lower Ordovicium (Tremadoc). In order to compare the results from Södra Sandby with those from other localities some samples of alum shale from this zone have been determined. The results are found in Table 8.

In samples 165-189 the isotopic composition of organic carbon has been determined, in samples 172-176 also that of carbonate carbon so that the isotope exchange

ratio (K') could be calculated for the three localities in Skane (see Fig. 1). A survey of the average values of $C^{12}/^{13}C$ and K' is presented below.

Locality	$^{12}C/^{13}C$ in organic carbon	carbonate carbon	K'
Motala, Östergötland	91·16	—	—
Skärlöf, Öland	91·21	—	—
Skåne :			
Södra Sandby	91·05	89·55	1·017
Gislövshammar	91·06	89·54	1·017
Andrarum	91·04	89·24	1·020
The Oslo region :			
Töyen, Oslo	91·11	—	—
Ringsaker, Mjösa	91·12	—	—
Vestfossen	91·04	—	—

Table 8

Dictyonema Shale from different Localities.

No.	*Level in bore profile*	$^{12}C/^{13}C$ *in organic carbon*	$^{12}C/^{13}C$ *in carbonate carbon*	*Locality :*
165	149·35-150·00	91·13	—	Motala, Sweden
166	150·00-151·00	91·30	—	,, ,,
167	151·00-152·00	91·16	—	,, ,,
168	152·00-153·15	91·03	—	,, ,,
169	27·70-27·90	91·24	—	Skärlöf, Öland, Sweden
170	27·90-28·20	91·23	—	,, ,, ,,
171	29·20-29·40	91·16	—	,, ,, ,,
172	39·00-39·50	91·05	89·70	Gislövshammar, ,,
173	37·00-37·50	91·00	89·36	,, ,,
174	37·50-38·00	91·12	89·50	,, ,,
175	36·50-37·00	91·06	89·56	,, ,,
176	38·50-39·00	91·05	89·57	,, ,,
177	5·58-6·00	90·94	89·12	Andrarum, ,,
178	6·00-6·50	91·00	89·12	,, ,,
179	6·50-7·00	91·08	89·15	,, ,,
180	7·00-7·50	91·04	89·40	,, ,,
181	7·50-8·00	91·12	89·12	,, ,,
182	8·00-8·50	90·95	89·49	,, ,,
183	8·50-9·00	91·09	89·19	,, ,,
184	9·00-9·50	91·06	89·23	,, ,,
185	9·50-10·00	91·07	89·21	,, ,,
186	10·00-10·50	91·09	89·32	,, ,,
187	—	91·11	—	Töyen, Oslo, Norway
188	—	91·12	—	Ringsaker, Mjösa ,,
189	—	91·04	—	Vestfossen, ,,

The isotope ratios in the organic carbon are rather similar in the cases investigated. The samples from the three localities in Skåne have the same ratio indicating a notable similarity of the source material. The isotope ratios in the carbonate carbon are equal for the Södra Sandby and Gislövshammar samples. The Andrarum Limestone on the other hand shows a slight decrease in the amount of the light isotope. This may be connected with the increase in stratified limestone (Andrarum limestone) occurring in this locality. As seen from Table 3, sample 41 this rock has a lower amount

of the light isotope which may decrease the isotope ratio in the calcite occurring in the milieu.

SHALES FROM DIFFERENT STRATIGRAPHIC ZONES

Some samples of black shales from the Oslo region have been placed at my disposal by Dr. ÖRVIK, Stockholm, and Dr. G. HENNINGSMOEN, Geological Museum of the University, Oslo. One sample (200) of the oil bearing shale from Esthonia derives from H. MUTVEI, Stockholm. The analytical results are presented in Table 9.

Table 9

Shales from different stratigraphic zones.

No.	*Stratigraphic zone and locality*	$^{12}C/^{13}C$ *in*	
		Organic carbon	*carbonate carbon*
190	Phyllograptus shale (3b), Oslo, Norway	91·11	—
191	,, ,, Modum, ,,	91·12	—
192	,, ,, Ringsaker, Norway	91·18	—
193	,, ,, Slemmestad, ,,	91·18	89·29
194	Ogygiocaris shale (4a), Ringsaker, Norway	91·05	88·83
195	,, ,, Slemmestad, ,,	91·07	—
196	,, ,, Frierfj, Brevik, Norway	90·60	—
197	,, ,, Jordal Amfi, Oslo, ,,	91·11	89·22
198	Tretaspis shale (4c) Nakholmen, Oslo, ,,	91·11	88·58
199	Limestone with *Peltura scarabaeoides* close below Ogygiocaris shale from Slemmestad, Norway	—	89·52
	Calcite vein in the shale	—	89·11
	Ogygiocaris Shale, Slemmestad, Norway	91·05	—
200	Oil bearing shale, Ubja, Esthonia	91·28	88·83

The variations in the isotope ratio in the organic carbon are about the same as those observed in the alum shale. Of interest is the considerable variations in the carbonate carbon, also illustrated in Fig. 7. In some cases - samples 193, 197 and 199 - the ratio is similar to that of the calcite in the alum shale. In other cases - samples 194, 198 and 200 - the ratio has decreased towards that of marine limestone in general.

THE ISOTOPE EXCHANGE IN MARINE SEDIMENTS

In the preceding sections the variations in the isotope ratio have been connected with the conditions prevailing during the deposition of marine calcite. Now the isotope exchange by the formation of carbonate will be considered.

The isotopic composition of a carbonate is largely determined by the isotope exchange reaction :

$$^{13}CO_2 + {}^{12}CO_3^{2-} \rightleftarrows {}^{12}CO_2 + {}^{13}CO_3^{2-}.$$

H. C. UREY and R. J. GREIFF (1935) have studied the thermodynamics of the above reaction and calculated the equilibrium constant *K*. Within the temperature range of marine sedimentation the *K*-values were: 1·016 at 273·1 °*K* and 1·012 at 298·1 °*K*. According to H. CRAIG (1953), however, the figures of *K* calculated by UREY and GREIFF are too high, since the average values used for the calculation were incorrect.

If using the average of the isotope ratio in marine limestone and in air, determined by CRAIG, and if presuming that isotope exchange equilibrium is attained the K-values mentioned above will be decreased to $K = 1{\cdot}008$ and $1{\cdot}006$ respectively.

According to F. E. WICKMAN (personal communication) the average isotope ratio of carbon dioxide in air from the Atlantic is 89·3 (on our scale). The ratio in marine limestone deposited in aerated and circulating sea water is estimated at 88·55. The isotope exchange ratio ($= K$) is then $89{\cdot}3/88{\cdot}55 = 1{\cdot}008$. Thus, the figures mentioned are consistent with those presented by CRAIG (1953). The conclusion

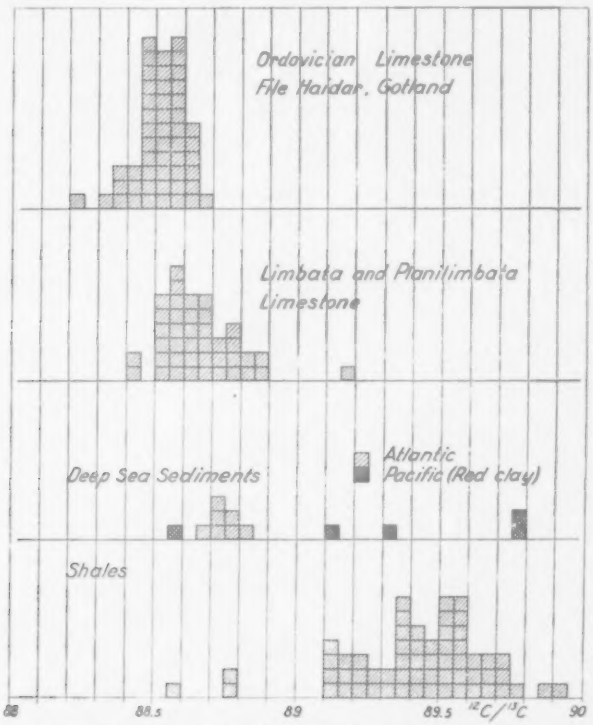

Fig. 7. A survey of the distribution of the $^{12}C/^{13}C$ values in the carbonate component of marine sediments. Each square = one analysis.

will be that limestones deposited under conditions mentioned are in isotope exchange equilibrium with carbon dioxide of the surroundings. Conversely, such limestones tend to isotope ratios of 88·5-88·6. No age effect is observed. (See Table 10).

It is essential for the discussion of possible hypothesis concerning the isotope exchange to ascertain whether or not variations in the isotopic composition of marine calcite is to be solely connected with the degree of attainment of equilibrium with carbon dioxide in the system : sea water – air. Clearly, slight variations in the ratio are accounted for by variations in temperature and rate of precipitation, as rightly emphasized by CRAIG (1953).

What is the probable cause of the considerable increase in the isotope ratio of the calcite component of bituminuous shales ?

The system : sea water – atmosphere may be regarded as a reservoir of carbon dioxide deriving from different sources. The formation of carbonate is a link of the carbon dioxide cycle of the sea, due to the main reaction :

$$CaCO_3 + CO_2 + H_2O \rightleftarrows Ca^{2+} + 2\,HCO_3^-.$$

The isotopic composition of the carbonate ions depends on that of the carbon dioxide of the surroundings. The isotopic composition of carbon dioxide is closely connected with the biochemical processes occurring in the sea. These processes are different in the surface and bottom water respectively.

Table 10

A Survey of the relative Abundance of the Carbon Isotopes in Marine Sediments.

	N	$^{12}C/^{13}C$ *avg*	$^{12}C/^{13}C$ *max*	$^{12}C/^{13}C$ *min*	*Percentage dispersion*
Carbonate carbon:					
Limbata Limestone					
Oxidized	15	88·56	88·67	88·43	0·27
Reduced	18	88·74	89·18	88·55	0·71
Total	33	88·66	89·18	88·43	0·85
Planilimbata Limestone	7	88·64	88·78	88·50	0·32
Ordovician limestone, File Haidar	51	88·52	88·67	88·24	0·49
Bituminous limestone	7	88·82	88·96	88·67	0·33
Deep sea sediments					
Equatorial Atlantic	7	88·74	88·80	88·67	0·15
West Pacific (red clay)	5	89·49	89·76	89·13	0·70
Alum shale, Södra Sandby	38	89·53	89·94	89·16	0·87
Dictyonema Shale	20	89·39	89·70	89·12	0·65
Sundry black shales	7	89·05	89·52	88·58	1·06
Organic carbon :					
Bituminous limestone	4	91·06	91·14	90·93	0·23
Deep-sea sediment					
West Pacific (red clay)	8	90·49	90·74	90·27	0·52
Alum shale, Södra Sandby	46	91.11	91·37	90·84	0·58
Dictyonema shale	30	91·08	91·30	90·94	0·40
Sundry black shales	11	91·08	91·28	90·60	0·75
(*N* = number of analyses)					

The photosynthesis takes place in the surface water. By this process carbon dioxide is assimilated by the plants. Since the rate of assimilation is a little greater of $^{12}CO_2$ than of $^{13}CO_2$ the carbon dioxide in the surface water will be somewhat enriched in the heavy carbon dioxide. The contribution of light carbon dioxide, due to decomposition of organic matter (respiration etc.) is comparatively small in this region. Anyhow, the carbon dioxide mixture will rapidly become homogenous, partly due to the circulation of the water and partly to the carbon dioxide exchange with the air.

The plants serve as food for the animals living in the surface region. Dead organisms sink gradually to the bottom region of the sea, where the decomposition of organic matter takes place, whereby carbon dioxide is produced on a comparatively large scale. Thus, the biochemical processes acting in the sea give rise to isotopic separation which is partly compensated by the circulation of the water.

If now the bottom water – for one reason or other – is stagnating the isotope ratio of carbon dioxide will increase and consequently also the ratio of the carbonate

ions formed in such a milieu. We have to reckon with the development of a local carbon dioxide cycle with more or less restricted communication with the surface water and the air. The magnitude of the isotopic ratio of the carbonate precipitated is obviously connected with the intensity of the local cycle and the amount of organically derived carbon dioxide involved in the cycle.

Now the question may be asked if equilibrium in the isotope exchange is attained under such conditions. To answer this question the alum shale milieu may be discussed.

As seen from Table 7 the considerable increase in the light isotope in the calcite component indicates that the carbon dioxide taking part in the isotope exchange to a great extend derives from decomposition of organic matter occurring in the milieu. The isotope exchange ratio – here called K' – is surprisingly constant throughout the alum shale profile investigated. The mean is 1·018 with a standard deviation of only $\pm$ 0·002. It goes without saying that the isotope exchange of this milieu tends to attain equilibrium; but since the isotope ratio of the calcite is 89·53 on an average, the isotope exchange and possible equilibration is quite different from that of the carbon dioxide cycle in the system surface water – air.

The K'-value is greater than K, quite naturally, since the carbon dioxide of the alum shale milieu not entirely derives from organic matter. A communication – certainly restricted – with the surface water must be considered, partly due to diffusion of heavy carbon dioxide from the surface region and partly to the contribution of calcite from shell bearing animals, where the isotopic composition of the shell calcite was equilibrated in the surface water. This means that carbon dioxide with an average isotope ratio of about 89·3 and calcite with a ratio of 88·5-88·6 are involved in the local carbon dioxide cycle developed in the alum shale milieu. If R_o is the isotope ratio of organically derived carbon, R_a that of water, R_c the ratio of the calcite precipitated in the milieu, and x the part of organic carbon taking part in the local isotope exchange reaction the true isotope exchange ratio = the equilibrium constant K will be :

$$K = \frac{R_o \,.\, x + R_a\,(1 - x)}{R_c} = K' \,.\, x + \frac{R_a}{R_c}(1 - x).$$

Since $R_a < R_o$ the true K-value $<$ 1·018 depending on the magnitude of x. If it is supposed that thermodynamic equilibrium is attained in the isotope exchange in the milieu where the alum shale investigated was deposited and K is estimated at 1·008, x can be calculated :

$$x = \frac{K \,.\, R_c - R_a{}^*}{R_o - R_a} = \frac{1{\cdot}008 \; x \; 89{\cdot}53 - 89{\cdot}3}{91{\cdot}11 - 89{\cdot}3} = 0{\cdot}52.$$

Thus, about $\frac{1}{2}$ of the carbon dioxide of the milieu should derive from organic matter. Anyhow, the constancy in the ratio K', presented in Table 7, indicates that a tendency to attain equilibrium in the local carbon dioxide cycle of the milieu is due to very stable and tranquil water conditions prevailing during the deposition of the alum shale discussed.

A few further examples of isotope exchange may be briefly mentioned. As seen

* $K.R_c < R_a$ indicates that no isotope exchange equilibrum between calcite and organically derived carbon dioxide of the milieu is attained.

from the survey on page 000 the K'-values of *Dictyonema* Shale from Södra Sandby and Gislövshammar are equal, indicating similar conditions during the deposition of the sediments from the two nearby localities. The Andrarum Shale has a little increased K'-value probably due to the increased amount of stratified limestone relatively enriched in the heavy isotope.

Of interest to note is the fact that the K'-values of some shales from different stratigraphic zones is higher than the corresponding values of alum shale.

Sample No.	K'
193	1·021
194	1·025
197	1·021
198	1·029
199	1·022
200	1·028

The increase in K' is obviously due to an increase in the amount of carbon dioxide emanating from aerated surface water thus involved in the local cycle.

In this connection attention should be paid to the K'-values of the bituminuous limestone (Table 3) occurring in connection with alum shale. Also in this case the calcite is enriched in the heavy isotope affecting the K'-value :

Sample No.	K'
41	1·022
42	1·024
43	1·028
44	1·006

With the exception of sample 44 – the K'-value of which seems rather doubtful – the values are somewhat higher than the average for the alum shale. The bituminous limestone occurs as small lenses or concretions in the alum shale. The increase in the K'-value indicates that the alum shale occasionally had a more unrestricted communication with the open sea with corresponding contribution of heavy carbon dioxide to the local cycle. As seen from Table 7 those K'-values tending to increasing figures compared with the average are from those samples taken in the immediate vicinity of bituminous limestone or stratified (Andrarum) limestone.

The K'-values of three samples of red clay from the Western Pacific are interesting. The K'-values are namely rather similar to the equilibrium constant K 1·007, 1·009, and 1·011 respectively. If isotope exchange equilibrium is presumed almost all carbon dioxide taking part in the formation of the minute quantity of calcite precipitated in this deep sea milieu should be of organic origin. As a matter of fact – according to oceanographers' opinion – the water conditions during the deposition of the very fine grained red clay have been very tranquil with no communication with surface water.

As seen from Fig. 5 the isotope ratio in organic carbon varies and may under certain conditions affect the ratio in the carbonate settled, for example in the alum shale milieu where organically derived carbon dioxide takes part in the isotope exchange. The cause of the variations in the isotopic composition of carbon derived from organisms is so far but little known. Since the plants serve as food for the animals

the variations in the isotopic composition of plants is of a primary interest. F. E. WICKMAN (1952) has studied these variations and he arrived at the conclusion that the enrichment of the light isotope is intimately connected with the intensity of the carbon dioxide cycle in the system : plant – soil (water) – local air – main atmosphere. It is of interest in this connection to note that the enrichment in the light isotope occurs in plants from stagnant water (intense carbon dioxide exchange). The amount of ^{12}C decreases in plants growing in non-stagnant water where no local carbon dioxide cycle can develope.

SUMMARY AND CONCLUSIONS

In the present study a large number of determinations of the carbon isotope ratio in marine sediments has been carried out. In some cases the ratio has been determined both in organic and carbonate carbon, so that the isotope exchange could be discussed. In the preceding sections it has been shown that the variations in the isotope ratio in marine limestone is affected by the water conditions prevailing during the deposition. Thus, the isotope ratio in limestone settled in circulating and aerated surface water tends to a value indicating that isotope exchange equilibrium with carbon dioxide of the system : is attained. If the communication with this system water-air is restricted and the deposition of limestone takes place in stagnant water an enrichment in the light isotope occurs to an amount depending on the amount of organically derived carbon dioxide involved in the local carbon dioxide cycle restricted to the system: bottom water-precipitate. In cases where the deposition of a carbonate component takes place under very stable water conditions – for example the alum shale milieu – the isotope exchange between carbon dioxide and carbonate tends to attain equilibrium.

ACKNOWLEDGMENTS

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Appendix : The Conversion of Organic Carbon to Carbon Dioxide and the Preparation of Barium Carbonate for Mass Spectrometric Determination

A. PARWEL

SAMPLES containing organic matter to be converted to carbon dioxide are often easily volatilized at rather low temperature (about 200°C). Hence it proved necessary to employ a special combustion technique. It is of great importance that the conversion is quantitative to avoid isotopic fractionation, as shown by P. BAERTSCHI (1952) and confirmed through experiments in this laboratory.

The combustion was carried out in a quartz tube 90 cm long. The tube was placed in an electric furnace divided into three sections so that the temperature of each section could be regulated independently. The quartz tube in the first section of the furnace

(about 25 cm long) was filled with a pelleted mixture of PbO_2 and asbestos. In the second section (about 30 cm long) the tube was filled with wire formed copper oxide. A quartz boat carrying the sample to be combusted was placed in the third section of the tube.

The oxygen gas used was purified from carbon dioxide by passing it through two absorption vessels filled with a 40 per cent solution of KOH. By passing CO_2-free oxygen through the combustion system for about two hours it was purified from carbon dioxide. Simultaneously the first and second sections of the tube were heated, the first to 200-220°C and the second to 650-700°C. The third section was kept cold.

The quartz boat carrying the sample mixed with copper oxide was placed in the third section of the tube and two absorption vessels, half-filled with glass pellets and 100 ml and 50 ml respectively of 0·3 N $Ba(OH)_2$ solution, were attached to the system. In cases where the conversion went very rapidly it was necessary to add a third absorption vessel in order to avoid loss of CO_2. The third section of the tube was then heated and the temperature increased to 700°C. The oxygen stream was regulated to a suitable rate. After four hours the conversion was completed. The amount of sample to be converted was chosen so as to give about 2 gr $BaCO_3$.

The precipitated carbonate was separated from the glass pellets by passing the contents of the vessels through a funnel. The pellets were washed with a little distilled water. The excess of $Ba(OH)_2$ was neutralized by 0·5N hydrochloric acid. The solution containing the precipitated barium carbonate was filtered off and the carbonate dried at 105-110°C and kept in well-stoppered glass tubes for subsequent estimation in the mass spectrometer.

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High pressure electrical lead-through plugs and gravity switches for deep-sea cameras

GEORGE SHUMWAY

(*Received* 4 *January* 1954)

Summary—Electrical lead-through plugs which allow insulated electrical leads to pass through a pressure case under high hydrostatic pressure, and high pressure gravity switches, have been developed for use in underwater photography. Pressure tank tests at 20,000 p.s.i., and limited use at sea, indicate that the devices are satisfactory for use at any oceanic depth.

INTRODUCTION

MANY attempts at underwater photography have been unsuccessful because of the problems of passing an insulated electrical lead through a pressure case under high hydrostatic pressure and of completing an electrical circuit deep in the ocean. The high pressure electrical lead-through plugs and high pressure gravity switches discussed here are practical solutions to these problems. It seems certain that in marine and oceanographic instrumentation other uses can be found for these devices, which are equally effective in deep and shallow water.

The most common method of passing an insulated wire or cable through a pressure case is by means of the packing-gland fitting. This type of fitting is entirely satisfactory for shallow water usage but in water deeper than 700-800 fathoms the pressure tends to intrude the cable, and the packing which surrounds it, into the pressure case. The packing gland is of little use on deep sea cameras because most of the deep sea floor lies at more than 1,000 fathoms.

EWING, VINE and WORZEL (1946) described an electrical lead-through plug which they used on deep sea cameras. Essentially their plug consisted of a brass screw insulated with plastic which passed through the pressure case. Outside of the case the screw terminated in a brass fitting which pressure held tightly against the case. Under pressure the plastic deformed sufficiently to make the fitting watertight. A single-conductor insulated cable connected to the brass fitting outside of the case, and the junction was insulated by tape or other suitable waterproofing material. Later, two O-rings were added to the fitting in somewhat modified form.

Two devices which have been used to complete an electric circuit to fire a deep sea camera on contact with the bottom are magnet switches and mercury switches. A tripping foot at the base of the camera provides the mechanism to activate either switch when the camera is lowered onto the bottom. The magnet switch consists of a non-magnetic pressure case containing a micro switch and a movable magnet plus a magnet outside of the case. The external magnet, which is moved by the tripping foot on the camera, activates the internal magnet which in turn activates the micro switch. The deep sea mercury switch utilizes a mercury switch contained in a pressure case. A switch of this type has been used for shallow water photography by the Marine Biological Laboratory at Plymouth, England (VEVERS, 1951); it

consists of a pressure case surrounding a mercury switch with a packing-gland fitting to exclude water. Gravity switches described in this report utilize the principle of the lead-through plug rather than the packing gland and hence can be used at much greater pressure.

HIGH PRESSURE ELECTRICAL LEAD-THROUGH PLUGS

Type used on USNEL deep-sea camera. A brass rod at the centre of this lead-through plug carries the electrical current through the case (Fig. 1). The rod is insulated from the metal outer part of the lead-through plug and from the pressure case by a

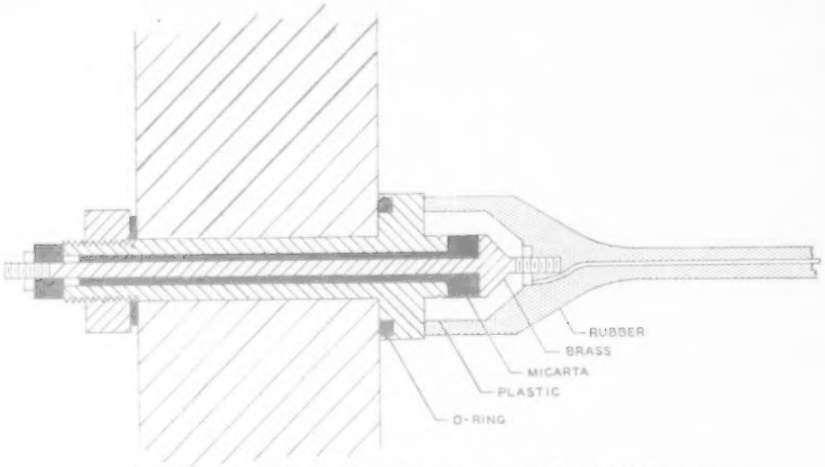

Fig. 1. High pressure electrical lead-through plug usable at any oceanic depth.

tube of insulation material such as Micarta. A shoulder at the outer end of the rod prevents it from being pushed into the case by the external pressure. The metal outer part of the plug is made from stainless steel and contains a recess for an o-ring of $\frac{7}{8}$ inch ID and $1\frac{1}{8}$ inch OD. It has a diameter of $\frac{1}{2}$ inch where it passes through the pressure case. Threads on the inner end of this piece make it possible to fasten the plug securely in place.

The central rod, the insulating tube and the metal outer part are held together by plastic which is cast around the outer end of the plug. A thermosetting plastic, NEL Compound 177 (ROLLE, 1950) is used, which adheres well to the three parts and effectively keeps out water.

The single conductor wire which connects to the lead-through plug is fastened to it by means of a nut which screws onto the portion of the central rod which projects through the plastic. Rubber is moulded around the end of the plug and is vulcanized to the rubber insulation surrounding the wire. By a conventional method the moulded rubber is bonded to the plastic and the projecting end of the brass rod.

In a pressure tank experiment this lead-through plug withstood a hydrostatic pressure of 20,000 p.s.i. for more than one hour without any sign of leak or failure. This pressure is greater than any oceanic pressure and therefore the plug is suitable for work in the very deepest parts of the ocean. Lead-through plugs of this type have been used with success on (fig. 3) the USNEL deep-sea camera (SHUMWAY, DILL,

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KIERSTEAD, 1954), however there has been no chance to lower the camera with this type of plug installed below 515 fathoms up to the time of this writing.

Simplified plug. A simplified lead-through plug can be made which is suitable for many purposes although it is not as rugged as the one already described. This plug eliminates the outer protective metal part and the cast plastic (Fig. 2). The main part of the plug is a piece of insulating material, such as Micarta, containing

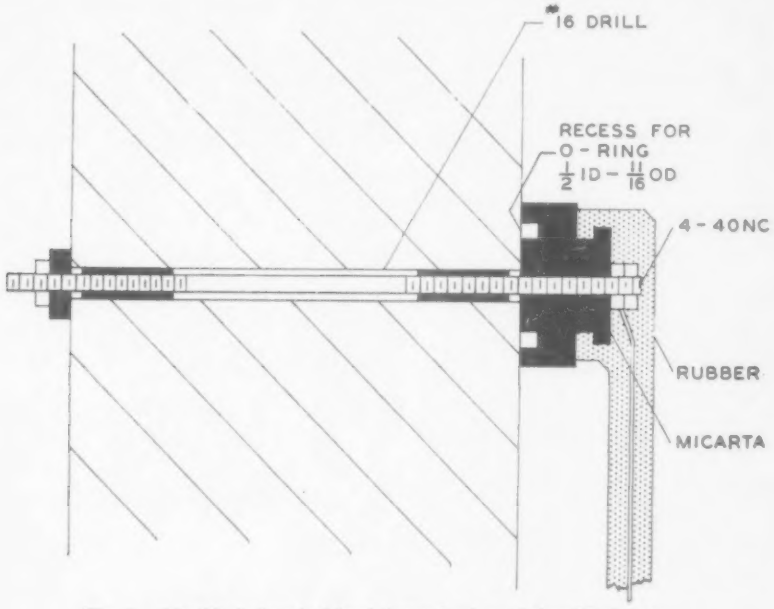

Fig. 2. Modified electrical lead-through plug of simplified design.

a recess for an O-ring of $\frac{1}{2}$ inch ID and $\frac{11}{16}$ inch OD. It is tapped for a 4-40 NC screw which passes through the case and is insulated from it by small pieces of fibre material of 0·177 inch diameter tapped for the screw. It is advisable to make the screw from steel because it alone must hold the plug in place. The insulated wire attaches directly to the screw at the outside end of the plug. Rubber is moulded around the end of the plug and is bonded to the Micarta by a standard method : the rubber also is vulcanized to the rubber insulation of the cable. For certain installations it may be advisable to have the cable join the plug perpendicular to the screw, for better protection of the plug, as Fig. 2 suggests. A plug of this type withstood a hydrostatic pressure of 20,000 p.s.i. in a pressure tank experiment.

HIGH PRESSURE GRAVITY SWITCHES

Mercury switch used on the USNEL deep-sea camera. A high pressure case can be made to surround a mercury switch (Fig. 4) by utilizing the principle of the lead-through plug. The main part of the pressure case is a stainless steel cylinder 1 inch in diameter with an $\frac{11}{32}$ inch diameter hole drilled in it to contain the switch. A stainless steel cap screws on the case to close it and an O-ring of $\frac{5}{8}$ inch ID-$\frac{13}{16}$ inch OD makes the pressure seal.

The mercury switch itself is made from a $\frac{5}{16}$ inch diameter plastic rod drilled out to $\frac{11}{64}$ inch diameter. Two metal contacts, made from steel paperclips, are contained in a cap which is cemented in the end of the tube. A special feature of the switch is the hole of reduced diameter at the end of the plastic tube opposite the metal contacts. This hole, $\frac{1}{8}$ inch in diameter, prevents the mercury from bouncing when the switch is tilted from the " on " to the " off " position by cushioning the mercury as it reaches the end of the tube.

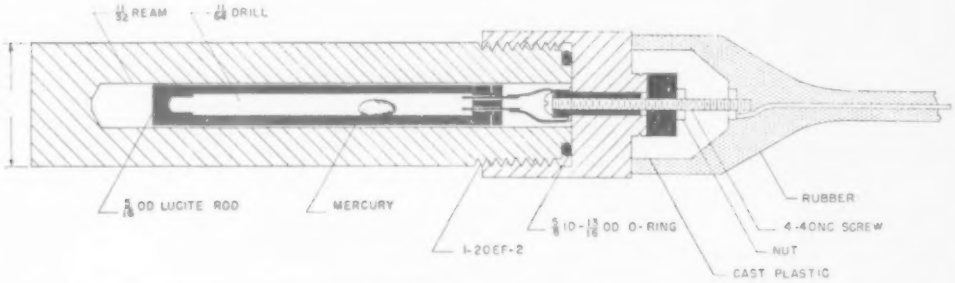

Fig. 4. High pressure mercury switch usable at any oceanic depth. Note that only one insulated lead passes through the pressure case.

The important detail which makes this high pressure switch feasible is that one of the contacts of the mercury tube is grounded on the cap of the pressure case. This means that only one insulated lead is required to pass through the pressure case. A 4-40 NC screw insulated from the metal cap carries the current through the cap. The screw is threaded into a piece of insulating material outside of the cap and a nut is added to help hold the screw securely. Plastic is cast around the end of the cap and turned on a lathe to proper size. Then rubber is moulded over the plastic and vulcanized to the rubber insulation of the cable which connects to the switch. The cast plastic is not essential, however, and could be eliminated as is shown in Fig. 5.

A switch of this type (Fig. 6) has been successfully used on the USNEL deep-sea camera (SHUMWAY, DILL and KIERSTEAD, 1954). It is rugged, compact, and dependable. In a pressure tank test the switch has withstood a hydrostatic pressure of 20,000 p.s.i.

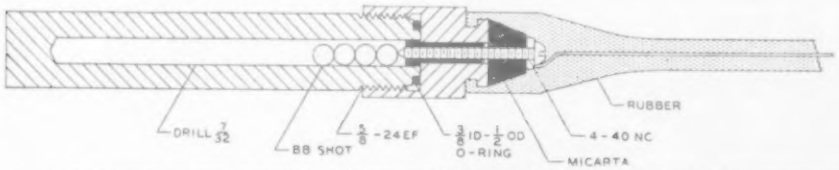

Fig. 5. A high pressure gravity switch utilizing metal BB-shot in direct contact with the pressure case.

Metal shot switch. A possible variation of the high pressure switch utilizes metal BB-shot in a brass tube in place of a mercury switch (Fig. 5). The metal shot complete a circuit between the case and the insulated screw which passes through the cap of the case. The inside diameter of the case is $\frac{7}{32}$ inch, which is small enough so that the entire case can be made of brass and still withstand high pressures. A single

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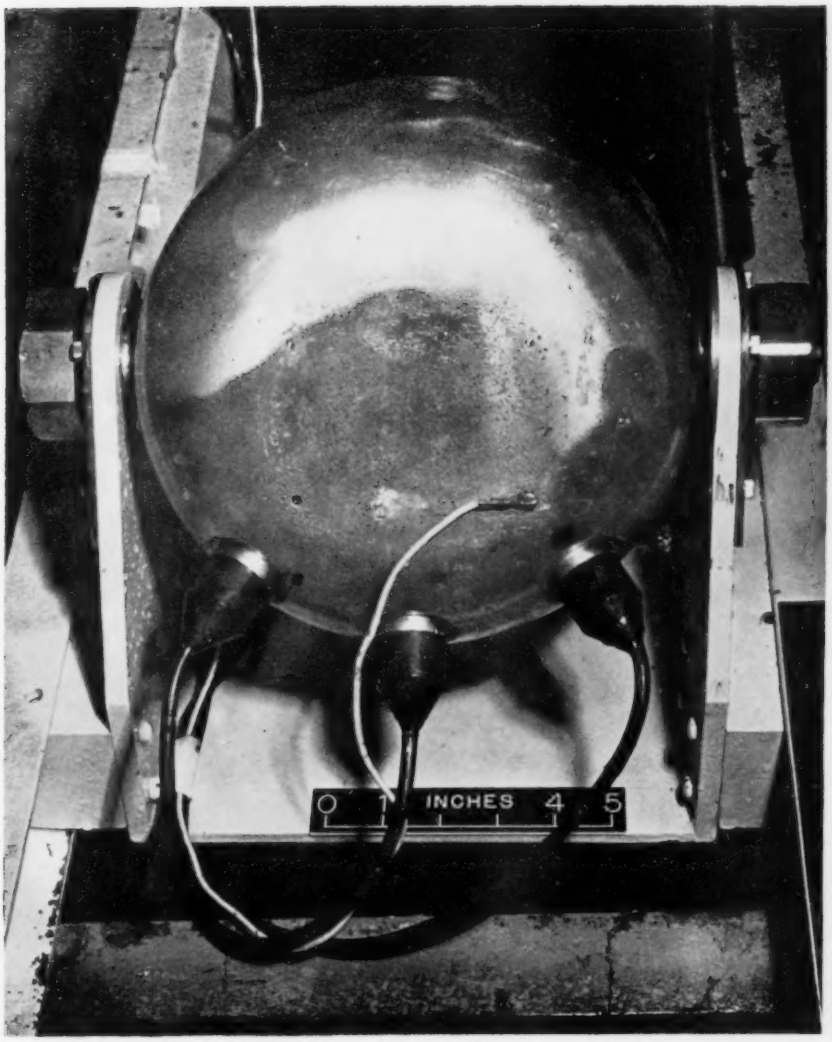

Fig. 3. High pressure lead-through plugs installed on a pressure case of the USNEL deep sea camera.

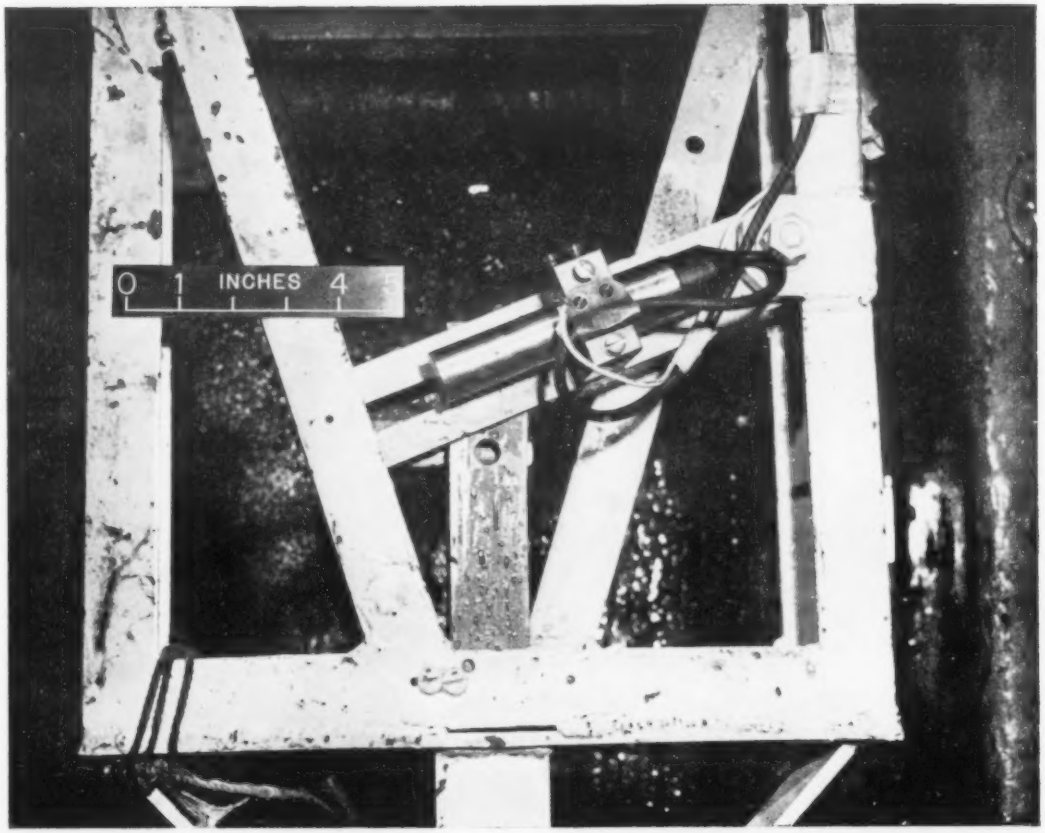

Fig. 6. A high pressure mercury switch installed on the USNEL deep sea camera.

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O-ring, $\frac{3}{8}$ ID by $\frac{1}{2}$ OD, forms the pressure seal between the cap and the case. The outside diameter of the brass case can be $\frac{5}{8}$ inch. The insulated lead is joined to the switch somewhat in the same manner as on the high pressure mercury switch, but plastic is not cast around the end of the plug.

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Les vases de la Méditerranée et leur mécanisme de dépôt

JACQUES BOURCART

LE travail essentiel sur les sédiments profonds de la Méditerranée est celui de BÖGGILD (Expédition danoise du Thor). THOULET, et son élève CHEVALLIER, puis surtout GEORGES PRUVOT, ont étudié la nature et la répartition des sédiments sur son Plateau continental.

BÖGGILD a établi que les sédiments profonds de la Méditerranée sont exclusivement des *boues bleues* (moins de 30% de $Ca\,CO_3$) et des *boues à globigérines* (plus de 30% de $Ca\,CO_3$). Il remarquait que la répartition de ces deux types de sédiments est absolument capricieuse ; elle ne dépendrait ni de la distance à la côte, ni de la profondeur.

Les dénominations de BÖGGILD me paraissent d'ailleurs mal choisies :

1. ces boues ont une couleur grise, grise-bleue, grise verte, verte ou, après oxydation, beige. Quelle que soit cette couleur, les boues contiennent toujours une forte proportion de $Ca\,CO_3$*, variant irrégulièrement dans l'espace et dans le temps, de 20 à 93%.

2. la proportion de Globigérines et même de Foraminifères pélagiques y est faible par rapport à la masse de poudre calcaire, dont l'origine est difficile à préciser, mais qui contient toujours une forte proportion de Coccolithophoridées.

3. la proportion des minéraux terrigènes, particulièrement de micas décolorés, est très supérieure à celle qui existe dans les boues à Globigérines océaniques. Le quartz ($< 200\,\mu$) y est toujours présent.

4. ces boues contiennent toujours (sauf quand elles sont beiges et oxydées) du sulfure de fer (hydrotroilite : $FeS\,.\,nH_2O$) et de l'humus.

5. leur composition les rapproche des vases péricontinentales atlantiques, des vases intermédiaires du Plateau continental (Grande Vasière) et même des vases d'estuaires. Dans toutes ces vases, seule est variable la proportion de quartz, micas et autres éléments terrigènes et aussi la concentration en humus. Elles sont aussi analogues aux " marnes bleues " du Pliocène et du Miocène, où seul le calcaire s'est en général concentré en nodules. Il nous parait donc plus convenable de leur donner le nom de " vases méditerranéenes."

Dans tous les cas, la composition des vases méditerranéenes est analogue. Elles comprennent :

1. un squelette avec de rares grains de *sable* (1·000 à 500μ) ; une phase de *sablon* (entre 200 et $20\,\mu$), surtout composée de mica noir décoloré avec quelques autres phyllites, des esquilles de quartz, des minéraux lourds (même à grande distance des côtes) et les restes calcaires ou siliceux d'animaux et de végétaux planctoniques et benthiques et de leurs larves pélagiques ; une phase *poudre*, essentiellement calcaire, provenant de la perforation des coquilles ou spicules et de débris de Coccolithophoridées et de Foraminifères. La proportion de phyllites et de " minéraux de l'argile," ainsi que de cendres volcaniques, y est très variable.

* Le $Mg\,CO_3$ qui n'a pas été dosé est exprimé en $Ca\,CO_3$.

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2. un liant, composé de sulfure de fer et d'humus, souvent associé avec de la silice et de l'alumine, probablement libres. Ce "complexe colloïdal" absorbe diverses substances organiques, notamment azotées. Sa proportion et sa composition (par exemple le rapport C/N) sont extraordinairement variables.

Dans les rades abritées et non ventilées, comme le fond de la Rade de Villefranche et la Rade de Marseille à l'Ouest des îles, ainsi qu' à l'extrémité des cañons sous-marins de la Baie des Anges, la proportion de liant peut être considérable. Les vases deviennent alors noires et leur teneur en eau incluse peut atteindre plus de 200% de la matière sèche.

Quand l'apport d'oxygène est abondant, les vases peuvent devenir beiges sur plusieurs centimètres d'épaisseur : le FeS se transforme en $Fe_2 O_3$ et l'humus est brûlé. Elles deviennent aussi beaucoup plus perméables.

Nous avons eu l'occasion de montrer dans de précédentes publications que, dans les mers à marées, il existe autour du littoral un ourlet de vase, chaque fois que le courant de flot, poussant à la côte de l'écume et des flocons, a une turbulence qui devient nulle. L'écume et les flocons sont des associations en *mailles* de particules minérales ou organiques de nature et de dimensions variées. Leurs parois sont solides parce que la somme algébrique des charges électrostatiques positives et négatives des particules qui les constituent est devenue inférieure aux forces d'attraction (forces de Van der Waals, etc.). La structure est en ruche d'abeilles et la vase est isotrope. La seule différence entre l'écume et les flocons, c'est que la première contient de l'air dans des mailles. Cet air peut disparaître par diffusion ou consommation bactérienne et les paquets d'écume se transforment en flocons, qui ont d'abord la densité de l'eau, puis deviennent plus lourds. La concentration des poussières a lieu surtout par suite de la pulvérisation de l'air dans la zone des brisants, phénomène analogue à celui décrit par Abribat pour la concentration di substances cares par les mousses. Lorsque, du fait de la baisse de la marée, la tranche d'eau qui recouvre le littoral est très mince, les flocons et l'écume se *collent* à tous les objets mouillés et lisses, particulièrement à la vase déjà déposée. Ainsi se forme les *slikke* ou les *wadden* (colmatage par "accrétion"). De telles vases ne se déposent pas seulement dans les estuaires, mais aussi sur le bord d'anses abritées : Honfleur, Baie de l'Aiguillon et de Fouras et à l'ombre d'îles, par exemple dans l'archipel de Bréhat. Les conditions de dépot de la tangue calcaire sont identiques.

D'autre part, L. Glangeaud a montré que, dans les grands estuaires comme la Gironde, la totalité de la vase ne se dépose pas sur les bords ; une grande partie se concentre en flottaison, sous forme du " bouchon vaseux". Celui-ci est formé de flocons qui perdent aussi progressivement leur air inclus ou adsorbé. Devenus un peu plus lourds que l'eau, ils se rassemblent en un *nuage de fond* que les plongées sous-marines nous ont fait connaître. Si la profondeur, la configuration de la côte ou l'étale de marée, suppriment toute turblence, ce nuage s'organise sur le fond en une vase cellulaire, très riche en eau incluse (de l'ordre de 300%). De très faibles courants, ou la seule agitation provoquée par les pales des plongeurs, suffisent à la remettre en suspension. Des remaniements successifs la condenseront jusqu'à une teneur qui, par exemple, ne peut être inférieure à 60% d'eau. Dans ces conditions, la vase devient très *rigide*. Expérimentalement, on peut réaliser cette concentration par des agitations successives. La vase cellulaire a une teneur en eau très supérieure

à celle de la "limite de liquidité" (d'Atterberg). Terzaghi a qualifié de telles formations de *sensitives*.

La répartition en Méditerranée des vases peut déjà nous éclairer sur leurs conditions de dépôt :

La *vase profonde* atteint 300 à 150 m sur le glacis qui borde le Plateau continental. Cette limite est reportée beaucoup plus haut lorsque le Plateau, défini à la manière classique, (comme la plaine entre 0 et 200 m) manque complètement. C'est le cas dans la profonde Baie des Anges entre Antibes (Fort Carré) et Nice. La vase y atteint presque le littoral ; elle monte le plus souvent dans les profondeurs de 20 à 25 m souvent à une distance de moins d'une cinquantaine de mètres de la laisse de mer.

Dans les Baies de Villefranche, de Beaulieu, d'Eze et de Menton, la vase s'arrête à une cinquantaine de mètres, à la limite où croissent les récifs à algues calcaires, support normal de "l'herbier." Mais, immédiatement en dessous de la ville de Villefranche, elle se dépose à nouveau dans une grande doline, à peu près isolée par une barre de grès quaternaire. Cette vase est normalement noire et dégage du H_2S. Une microfalaise la limite vers le large, due à l'arrêt de la prolifération des organismes récifaux.

Dans le Golfe du Lion, où ilya un large Plateau continental en très faible pente, on rencontre au delà des " sables roux " (ou sables du large) qui recouvrent jusqu'à 100 m. son bord vers le large, une bande de vase intermédiaire qui monte au moins à 70 m, parfois à 40. Vers la terre, avant la rencontre des sables et graviers du prisme littoral, elle est bordée de sables très analogues à ceux du large, de couleur également rousse.

Cette disposition, qui avait été découverte à Banyuls par Georges Pruvot, se reproduit dans le Golfe de Gascogne, où la Grande Vasière s'étend dans la même situation entre Bordeaux et Audierne. Des sortes de détroits l'interrompent où les deux bandes de sable roux se réunissent l'une à l'autre. Il en est de même de la côte atlantique du Maroc et de certaines parties de la côte orientale des Etats-Unis. Bien que cette disposition semble avoir une certaine généralité, la vase intermédiaire peut manquer par exemple quand le Plateau est *rugueux*, comme entre le Cap Cantin et le Cap Rhir au Maroc et sur les bancs méditerranéens (Banc des Blauquiéres, Banc du Magaut).

La raison du manque de vase dans la zone des sables du large n'est pas encore bien connue. Nous avons reconnu que ceux-ci contiennent souvent des éléments planctoniques, mais surtout siliceux, comme des spicules d'Eponges et des Radiolaires, parfois même des Diatomées. Les remplissages des tests des foraminifères ou des frustules de diatomées par du FeS, sont transformés en Fe_2O_3. Il semble bien qu'ils évoluent progressivement en glauconie imparfaite (*imperfect casts* de Murray). C'est donc une zone d'oxydation. L'eau y est même assez pure et aérée pour permettre occasionellement, à des Laminaires (*L. Caulini*) d'y vivre. Il existe, entre cette zone et le rebord des parois des cañons sous-marins, une très grande analogie au point de vue biologique et biochimique. Le fer et le manganèse s'y déposent sur des coquilles ou des coraux qu'ils peuvent même arriver à cimenter. Dans ce cas, le ciment ferrugineux remplace progressivement la calcite des coquilles.

Tout ce qui vient d'être écrit évoque une grande turbulence de l'eau dans la région de changement de pente. Très nette en Méditerranée, elle est impossible àlmettre au compte des courants de marée. Serait-elle due, comme l'a pensé KUENEN,

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au Crusque *freinage* des plus grandes lames et à la turbulence qu'il provoque ? Mesures de courants et photographies sous-marines permettront peut-être de résoudre le problème.

Les vases se déposent aussi, comme nous l'avons vu, à l'abri des jetées des ports et dans les rades protégées de certains courants, comme la moitié occidentale de la Rade de Marseille. Elles sont aussi riches en $Ca\,CO_3$ et en éléments planctoniques, même profonds, que les vases intermédiaires et du large, très riches aussi en feuilles et poils de Posidonies. La proportion de carbone et d'azote et surtout de sulfures est tout à fait anormale. L'exemple le plus intéressant à étudier est celui de la doline du fond de la Baie de Villefranche. Certaines années, où semble-t-il domine le vent d'Est, des dépôts de sables fins, apportés du littoral, remplacent la vase et il n'y à plus de dégagement de H_2S. Il semble que les éléments qui constituront la vase sont apportés par des courants froids ascendants (upwelling) qui se produisent sous l'effet du vent d'Ouest (appelé ici le mistral). Des courants profonds, en sens inverse, peut être des " courants de turbidité," se produiraient par vent d'Est et quand une houle importante rentre dans la Rade.

Nous nous sommes livrés pendant quatre ans à l'étude des variations de composition chimique des vases dans la partie profonde de la Rade ; les résultats étant exprimés en courbes isarythmes. Il semble que le calcaire de sa partie fine (passant au tamis de 350) *provienne toujours du large* et qu il s'y étale par mistral, comme une inondation. Au contraire, les courants qui résultent du vent d'Est semblent *creuser*, dans la vase sensitive, un véritable réseau de talwegs qui se remplissent progressivement de vase beaucoup plus sableuse. Les carottages montrent que les variations annuelles sont toujours irrégulières suivant les points.

La vase planctonique se dépose sur le remplissage des cañons sous-marins. Lorsque ceux-ci atteignent le littoral, par exemple au Trou de Carras, à moins de 20 m de la Promenade des Anglais à Nice, dans la zone des sables littoraux ou dans le cañon du Var, immédiatement contre la barre de galets qui ferme le fleuve, c'est encore de la vase planctonique que l'on peut récolter. Lors des crues du Var, les éboulements de la barre et les courants de turbidité y font pénétrer sables et galets rapidement ensevelis dans la vase pendant le long étiage. Dans la plupart des cañons, un *bouchon de sable* obture le cours supérieur jusqu'à une profondeur variant de 90 m à 40 m. Il est également du à des courants de succion qui entraînent les sables du Plateau continental dans le cañon. Sur la côte algérienne, extrêmement inclinée, des courants de turbidité peuvent ainsi convoyer des sables au milieu de la vase profonde, jusque dans les fonds de 2.900 m.

COMPOSITION MOYENNE DES VASES MÉDITERRANÉENES

Les mesures que nous avons faites de Banyuls à Villefranche et les analyses de deux radiales, de Marseille à Ajaccio et au large de Monaco, nous ont montré, une variation irrégulière de la composition chimique de ces vases. Mais leur composition moyenne est reserrée dans des limites assez étroites.

Voici, pour ce qui est de leur constituant le plus caractéristique: le carbonate, les valeurs minima et maxima ainsi que les moyennes. Il s'agit de la phase plus fine que 4μ, passant au tamis 350 : "*fine washings*".

Proportion de carbonates, exprimée eu Ca CO_3 %, dans les vases

	Année	Nombre d'analyses	Min.	Max.	Moy.
Banyuls					
vases côtières		(35)	23	70	39·80
du large		(35)	25	47·5	31·4
moyenne générale		(70)			32·6
Baie des Anges	1947	(5)	8·9	21·2	16·8
	1951	(50)	39·2	64·7	53·59
	1952	(43)	40·7	62·3	54·40
Villefranche	1946	(10)	40·9	74·5	55·4
	1947	(5)			23
	1950	(50)	25	92·8	51·2
	1951	(33)	31·78	70	48·5
	1952	(39)	45·7	69·5	59
Cable Marseille-Ajaccio	1947	(12)	27·4	56·7	41·74
Monaco (300-520 m.)	1947	(13)	25·1	37·1	30·6

Les analyses des vases de la Grande Vasière (Penmarch, 1947) nous ont donné une moyenne de 20% de Ca CO_3, celles des vases du Maroc (1948): de 23,2% (minimum 14,4 maximum 30,8). Le nombre d'analyses est insuffisant pour assurer qu'elles sont moitié moins riches en carbonate que les vases méditerranéennes.

De ces observations qui doivent être encore prolongées il nous semble ressortir que :

1. la vase de la Méditerranée provient essentiellement d'un matériel planctonique et d'un matériel flotté entraîné au large par de grands tourbillons horizontaux fixés entre les presqu'îles : flocons contenant des grains de sable quartzeux et des micas, des Foraminifères littoraux remplis d'air (*Rotalia Beccarii* p. ex.). Ce matériel descend lentement vers le fond lorsqu'il perd l'air inclus ou adhérent ; il forme un nuage qui peut nourrir la vase précédemment déposée ; une autre partie est poussée à la côte par les courants de fond.
2. le nuage se dépose dans les petits fonds quand la turbulence y est nulle (cañons, fosses et creux, abris naturels et artificiels).
3. lorsque une " rugosité hydrodynamique " suffisante existe sur le fond : bord du Plateau continental, bordure des cañons, hauts fonds le nuage ne se dépose pas.
4. la vase se fixe sous forme spongieuse, hyperthixotropique (sensitive). Elle peut alors être remainiée par les plus faibles courants et se redéposer avec une teneur en eau et une rigidité de plus en plus forte.

Aucune détermination granulométrique ou chimique ne peut nous permettre actuellement d'indiquer, à coup sur, à quelle profondeur s'est déposée une vase ancienne. La nature des tests de Foraminifères morts n'est pas plus significative. La présence de Foraminifères arénacés peut nous renseigner plus utilement. Il faut toutefois remarquer que la répartition des faunes semble plutôt liée aux variations thermiques qu'à la profondeur elle-même.

Villefranche sur Mer.

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Deep-Sea Research, 1954, Vol. 1, pp. 131 to 140. Pergamon Press Ltd., London.

Precision measurement of ocean depth

BERNARD LUSKIN, BRUCE C. HEEZEN, MAURICE EWING and MARK LANDISMAN

Summary—An instrument for recording ocean depth to an accuracy better than one fathom in 3,000 fathoms has been constructed and tested at sea. The instrumentation includes the electronic portion of any of the standard deep sea echo sounders, a modified facsimile receiver, an additional open scale recorder, and appropriate gating, switching, filtering, and monitoring equipment for connecting them. Data from over 1,300 miles of track has been obtained from the following general topographic provinces of the North Atlantic : the Continental Rise, the basin west of Bermuda, the Bermuda Rise, the Nares Basin, the Outer Ridge, and the Puerto Rico Trench.

Recent studies of submarine topography, deep sea sediments, and suboceanic crustal structure have emphasized the need for an accurate instrument of high resolution. The relationship between the seaward extension of submarine canyons and the gradients of the abyssal plains, in particular, can now be explored in detail. The data provided by this instrument greatly aid in the efficient utilization of deep sea corers, dredges and cameras, and in the intelligent interpretation of the data obtained from these and other instruments of oceanographic research.

With further development of this instrument, it is anticipated that data will be obtainable on such phenomena as waves and tides in the deep ocean.

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INTRODUCTION

THE need for an instrument of high resolution for recording ocean depth has been emphasized by the results of studies made at the Lamont Geological Observatory over the past five years. During this period, much information has been accumulated and studied, and a coherent picture of the morphology and structure of the Atlantic Ocean is emerging. TOLSTOY and EWING (1949) and TOLSTOY (1951) described the general features of the topography of the North Atlantic by correlating about 150,000 miles of continuous echo sounding records. The study of hundreds of cores by ERICSON, EWING and HEEZEN (1951, 1952) produced strong evidence that the major agent which is active in modifying submarine topography is the turbidity current (HEEZEN, EWING and ERICSON, 1951). Photographs of out-crops by NORTHROP and HEEZEN (1951) and analysis of submarine cable breaks by HEEZEN and EWING (1952) showed that turbidity currents are active at the present time and are powerful transporters of large quantities of sediment. The recent exploration of 1,200 miles of a canyon in the center of the Labrador and Newfoundland Basins provided an excellent opportunity to obtain information on sediment deposition processes in deep sea basins by the action of turbidity currents (EWING *et al.*, 1953). In all these studies, a severe limitation was the inadequate resolution and accuracy of the echo-sounding equipment. For example, the surveys of the Hudson Canyon and the Mid-Ocean Canyon were both terminated by the limits of resolution of the depth-measuring equipment. The inaccuracy of this equipment also seriously hindered the investigation of the abyssal plains. TOLSTOY (1951), discussing apparent step-like breaks in the abyssal plains of the North Atlantic states, " However, it is impossible in many cases to identify the boundary between these levels, since changes in depth of the order of 50 fathoms are very difficult to correlate from soundings by different ships or even different cruises of the same ship. The combined effects of small frequency

changes in the instruments, of differences of sound velocity in the sea water, and of calibration may be of the order of 50 fathoms."

In the experience of the authors and their associates, the greatest deficiency of modern echo-sounding equipment is the lack of precise and accurate recording apparatus. The earliest deep-sea soundings were made with hemp rope and required that the ship be stopped for many hours. The introduction of piano wire sounding machines eliminated the need for storing large volumes of rope, but did not greatly reduce the time required for a sounding. The determination of depth by means of the time required for obtaining an acoustic echo from the ocean bottom was proposed as early as 1807 by ARAGO, but his suggestion was 104 years old before R. A. FESSENDEN invented the oscillator which made continuous echo-sounding tracks practicable from a ship under way at full speed (ADAMS, 1946). Continuous recording of depth as a function of time was not introduced until the 1930's and its use was confined to depths less than 2,000 fathoms. Modern instruments, with their efficiently designed electronic systems, are able to provide continuous sounding records at all oceanic depths, and ships such as the Research Vessel *Atlantis* have made continuous depth recordings over several hundred thousands of miles of track. However, modern recording apparatus, while possibly adequate for navigation and coarse surveying, is far from meeting the demands of present-day oceanographic science.

Although the instrument reported on here is considered to be only an initial development toward providing a scientific tool for oceanic depth measurement, the first sea trials have already provided much useful data not available before. Furthermore, the results obtained indicate that further effort expended on development of such a tool will be fully justified.

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INSTRUMENTATION

The echo-sounding equipment discussed here is shown in block diagram in Fig. 1 and a photograph of the recording apparatus is shown in Fig. 3.

The transducer of the deep sea echo-sounder, which is used for both transmission and reception of the acoustic pulse, was towed on a length of cable from a forward location alongside during most of the trails.* The transmitting and receiving circuits of the instrument were used but recording of the transmitted and reflected pulses was done on 2 modified spark type facsimile receivers such as are used in the transmission of pictures by wire or radio. The facsimile receiver consists of a tuning fork power supply, a synchronous drive rotating a recording drum at 120 r.p.m., electronic circuits for supplying voltage to a stylus which prints by spark discharge on a standard facsimile paper, and a stylus translating mechanism driven by a separate motor. The recording paper is used in sheets approximately 28 x 48 cm at the rate of one sheet per hour. The scales are 1 fathom = 2·4 mm for the standard velocity of 800 fathoms per second, and 5 minutes = 2·5 cm. The rotating drum closes the keying contacts of the echo sounder transmitter through a keying gate every $\frac{1}{2}$ second. The gate is set manually for a recurrence rate appropriate to the depth and allows a group of 4 or 5 pulses to be sent at $\frac{1}{2}$ second intervals. The first of the series of transmitted pulses operates a recording gate which short-circuits the input to the facsimile

* In towing a " fish " from a cable over the side of a ship it is extremely difficult to stabilize the " fish " in such a way that it is always (on the average) directed vertically downward. Appreciable tilt aft was observed on records on recent cruises. This resulted in different echo intensities depending on which way the ship was steaming over the same feature.

recorder for a pre-set interval. Thus, the fast recorder prints only a small part of the transmitted pulse, none of the reverberation, and only for the gated interval set by the operator to include the time of the bottom-reflected pulses. The operator of the recorder monitors the recorder input both aurally and visually so that he may set the gates for a minimum of unwanted recording. In order to check the constancy

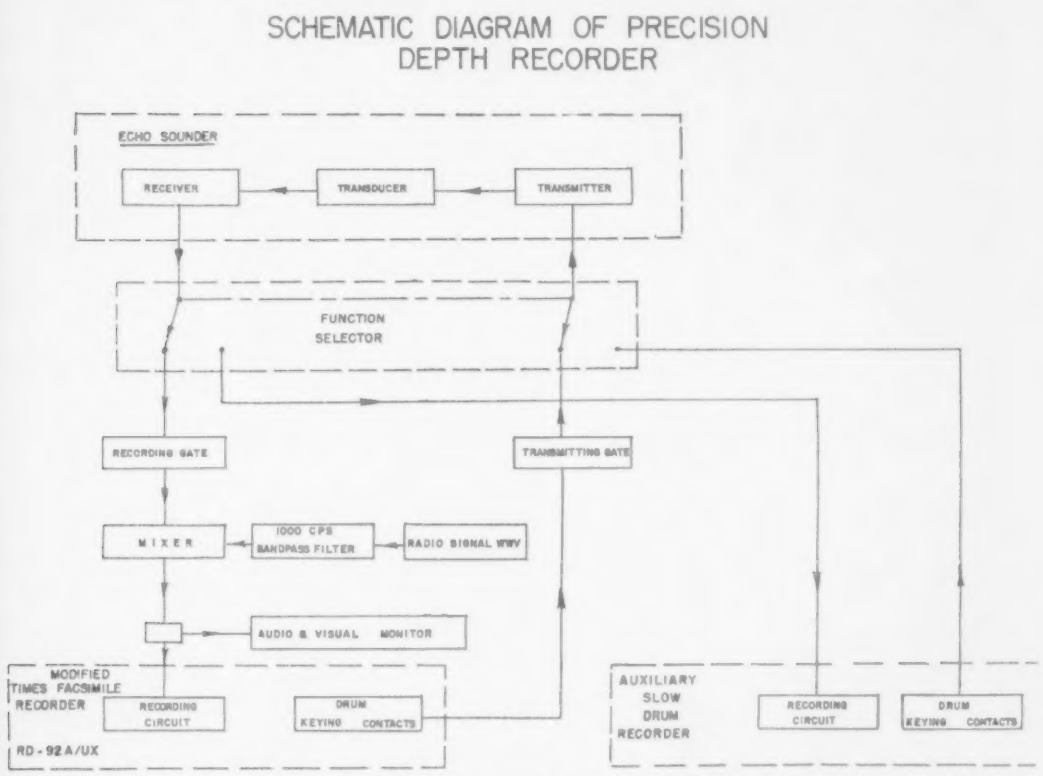
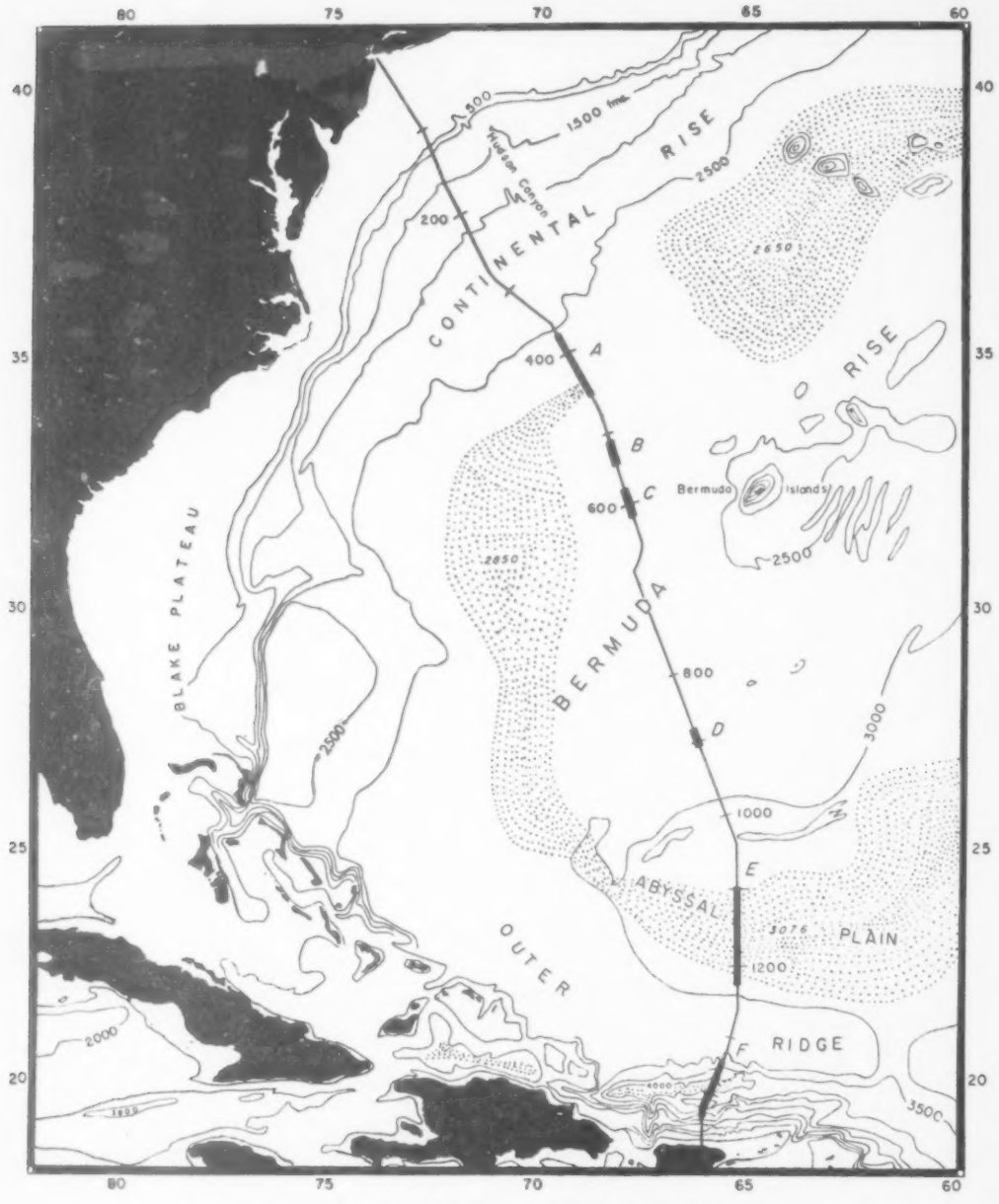


Fig. 1. Schematic diagram of the Precision Depth Recorder.

of rotational speed of the drum, the 1,000-cps pulse which is transmitted every second by the National Bureau of Standards' Radio Station WWV may be recorded when desired.

The facsimile instrument used was model RD 92A/UX Facsimile Receiver manufactured by the Times Facsimile Corporation of New York which incorporates a tuning fork power supply with a guaranteed stability of 3 parts per million for a 20°F ambient temperature change. For the purpose of echo-sounding recording, the standard model was modified to run at twice its normal speed of 60 r.p.m., the stylus was redesigned to eliminate bounce at the new speed, and an independent traversing drive was added to translate the stylus. Although the higher speed presents greatly increased loads to the drive mechanism, there is no indication from tests made so far that the original machine's specifications are not met by the modified version.

Fig. 4 shows a one-hour recording of WWV time signals. The recording of the



Contours in fathoms from Tolstoy (1951) and Heezen (in Ewing and Worzel 1953)

Distances in nautical miles from New York along track of R/V Vema (cruise 1)

— Illustrated profiles Abyssal Plain

Fig. 2. Chart showing track of the *Vema* (Cruise 1)

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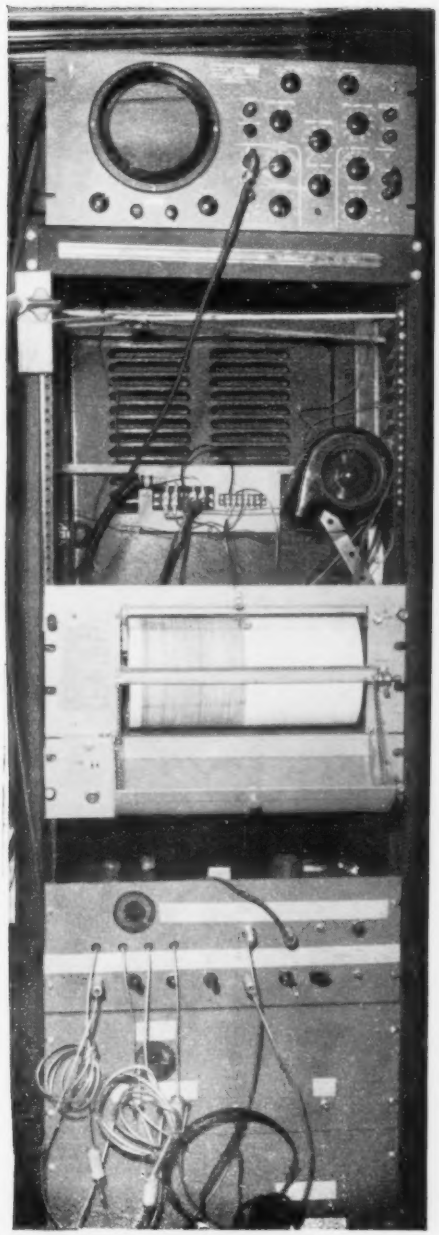

—Monitoring oscilloscope.

—Space for "Slow" 0—4800 fathoms scale drum (removed).

—Cooling fan.

—"Fast" drum recorder 200 fathoms full scale.

—Grating, monitoring and filtering circuits.

Fig. 3. Photograph of the apparatus in use.

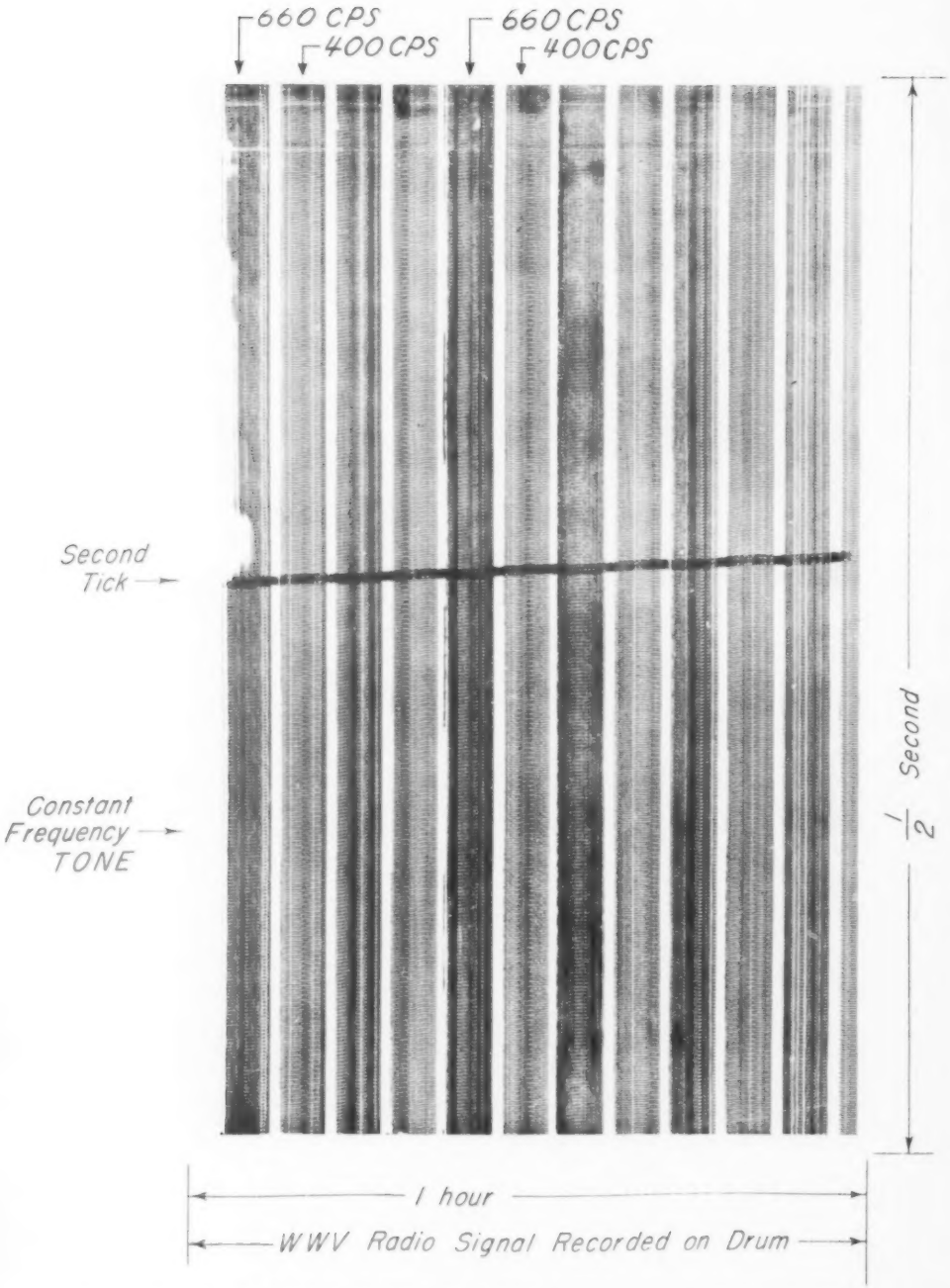

Fig. 4. Record of WWV Radio Time Signals illustrating constant rate of revolution.

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600 cps and 440 cps tones of WWV which are transmitted for 4 minutes every alternate 5 minutes shows slight variations due to the changing propagation path of the radio waves. The dark band is the record of the second ticks which was used to check the echo-sounding records. It can be seen that the fork rate is nearly constant. It was later adjusted to zero, but the error in depth determination due to the fork rate shown in Fig. 4 is only about 1 inch in 3,000 fm.

The use of the facsimile recorder drive for both recording and keying has eliminated the problem of timing caused by uncertain " scale value " in earlier instruments, and the use of a single stylus to record both the outgoing signal and the echo has eliminated uncertainty of the zero point. The phenomena of 59 cps " hills " and 61 cps " valleys " are familiar to every experienced observer of echo-sounding apparatus at sea. The facsimile recorder drive has reduced these errors by approximately two orders of magnitude.

The use of a recorder with a full scale of 200 fathoms could cause confusion in measuring the depth in a previously unsurveyed area or in rough terrain. The auxiliary slow drum recorder with a fork-controlled drive for both keying and recording was needed to specify the coarse measurement of depth, and was added shortly after the first leg of Vema Cruise Number One.

The slow drum only records for 20 seconds every 3 minutes. During these times a selector circuit allows it to take over completely the keying and recording functions of the apparatus. While the slow drum record is being made, the fast recorder continues to turn but does not record, so that its records have small samples removed, which serve as time reference marks.

The 4,800 fathom scale of the 5 r.p.m. slow recorder is represented by $18\frac{3}{4}$ inches of chart. Its recording stylus translates from left to right, covering the entire 12-inch chart in 24 hours. It thus furnishes a coarse record of the depth at any time, records the deep scattering layers and presents a summary of the topographic profile surveyed during the day.

The time scale has proved to be slightly too compressed, and doubling the speed of translation and rotation is indicated. A full chart would then last 12 hours.

LIMITATIONS IN THE PRECISE MEASUREMENT OF OCEAN DEPTH

The instrument described here has a timing accuracy equivalent to about $\pm$ 1 foot in depth. However, other factors must be taken into account when considering the determination of absolute depth. Translation along the vertical of the transducer platform introduces error. However, except for longer period variations such as the tide, these motions are averaged out.

Large corrections for variations in the average vertical velocity of sound must be made if absolute depths are required. These variations are functions of both location and time, and the available data on them is generally inadequate for precision echo-sounding purposes. However, the vertical sound velocity is usually relatively constant in any one area, and it is not always essential to know the exact vertical sound velocity in order to study the details of the bottom relief. The regional tables of mean vertical velocities for echo-sounding most generally used are those of MATTHEWS (1939) states that his accuracy is no better than $\pm$ 1 m/sec at 4,000 m, and the extrapolation of the tables downward " may be done with great accuracy when depth exceeds 4,000 m." On the basis of reproducibility of our measurements it is

estimated that the measurement of depth made with the precision depth recorder is good to better than one fathom in 3,000 fathoms, excluding uncertainties in the speed of sound in sea water. It is interesting to note that MATTHEWS believes the errors due to the use of averaged velocities to be much less than " other errors unavoidably attached to an echo sounding," among which he lists " irregularities in the rate of the motor of the sounding machine " (MATTHEWS 1939). We believe that the precision echo sounder has reduced all other sources of error to such an extent that the uncertainty in the speed of sound in sea water and the slope of the bottom are the principal sources of error in absolute depth.

A precise knowledge of the actual value of the sound velocity is unnecessary if only relative topographic information over a small area is desired, where there is no reason to assume a horizontal discontinuity in the sound velocity, e.g. a strong current. For example, consider the information obtained from the echo-sounding in the Puerto Rico Trench (Fig. 7). Here we may reasonably assume that the sound velocity is constant over the 10 miles of track covering the trench bottom. We see that the bottom is essentially flat with a slight slope down toward the south, there is a hill or ridge about 125 feet high near the middle of the trench, and the sides of the trench rise steeply at an angle of at least 8 degrees. The precise depth of the bottom is less important than this information. In fact it is standard practice among submarine geologists and hydrographers to use echo-soundings uncorrected for the variations from the standard sound velocity of 800 fathoms per second (cf. HESS 1948 and TOLSTOY 1951).

There are other problems which require knowledge of the average vertical sound velocity to the desired accuracy of depth measurement. One of these of particular interest is the measurement of the gradients of the abyssal plains. Here we wish to detect small depth differences over wide areas, and an assumption of constant velocity will not be justified. Better information on velocity is necessary if the full capabilities of the precision recorder are to be utilized. This may be obtained by using hydrographic stations in the areas of investigation for more detailed information on temperatures and salinities, and may ultimately require revision of the tables for the effect of these upon sound velocity, or even a direct survey of the sound velocity.

SEA TRIALS

The transducer was towed from a cable attached well forward on the ship according to the technique used by HERSEY and VINE at the Woods Hole Oceanographic Institution. The first tests were made from the Research Vessel *Atlantis* (Cruise 184) on March 16-17, 1953 in the flat floored basin which lies between Hispaniola and the Bahama banks. In order to obtain readable records the ship's speed had to be reduced to 4 knots. The first tests showed that the precision recorder as designed could obtain accurate records of high resolution if the signal-to-noise ratio could be improved. The higher recording speed of the facsimile recorder required a sharper beginning and end of the received echo, if the bottom recording was to have clear edges. The signal-to-noise ratio of the standard deep sea-echo-sounders proved insufficient at the new recording speed. In addition, the fast drum was accumulating noise continuously, while it only received echoes during a small percentage of the time. The use of gating circuits and groups of transmitted pulses was deemed a

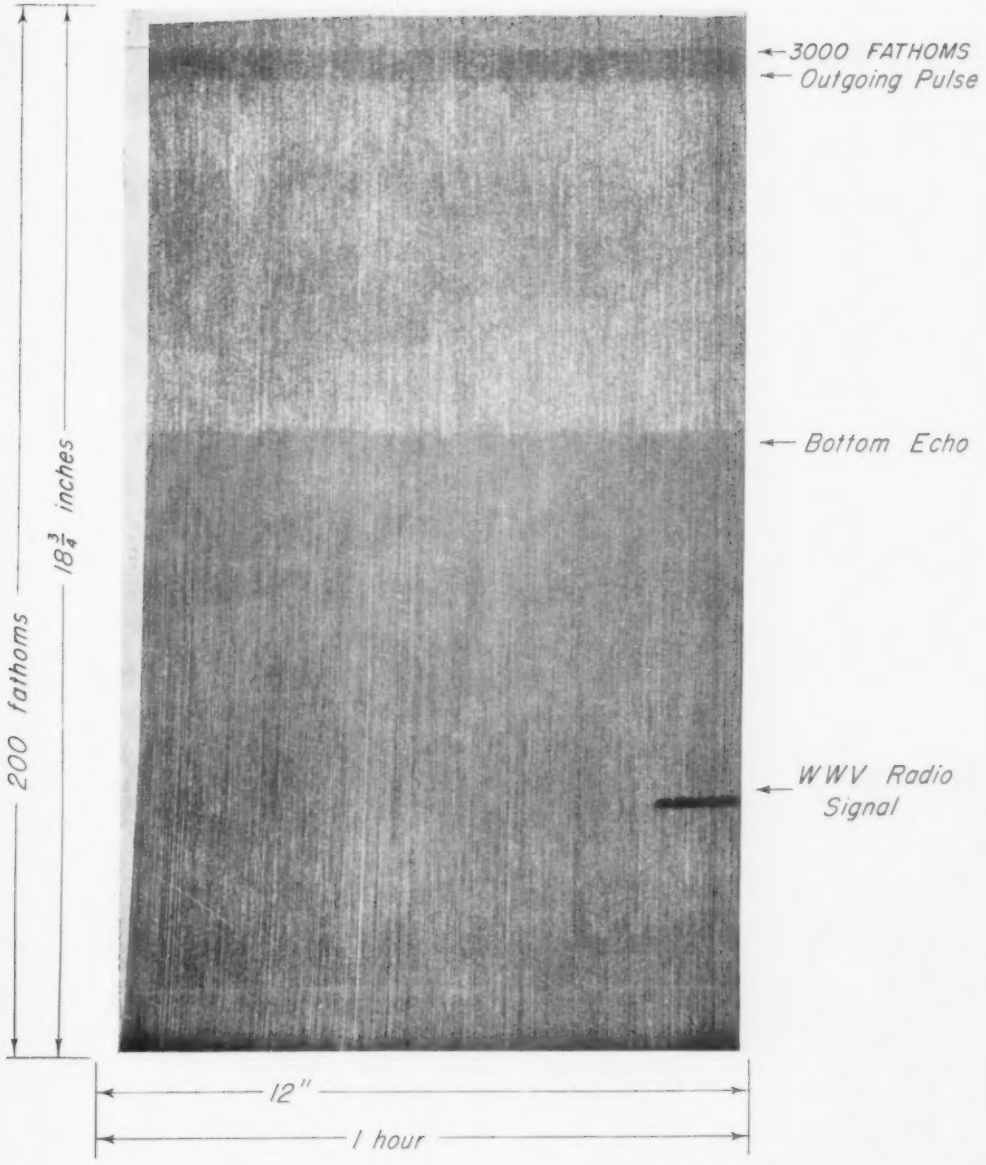

Fig. 5. Typical depth record from the abyssal plain of the Nares Basin.

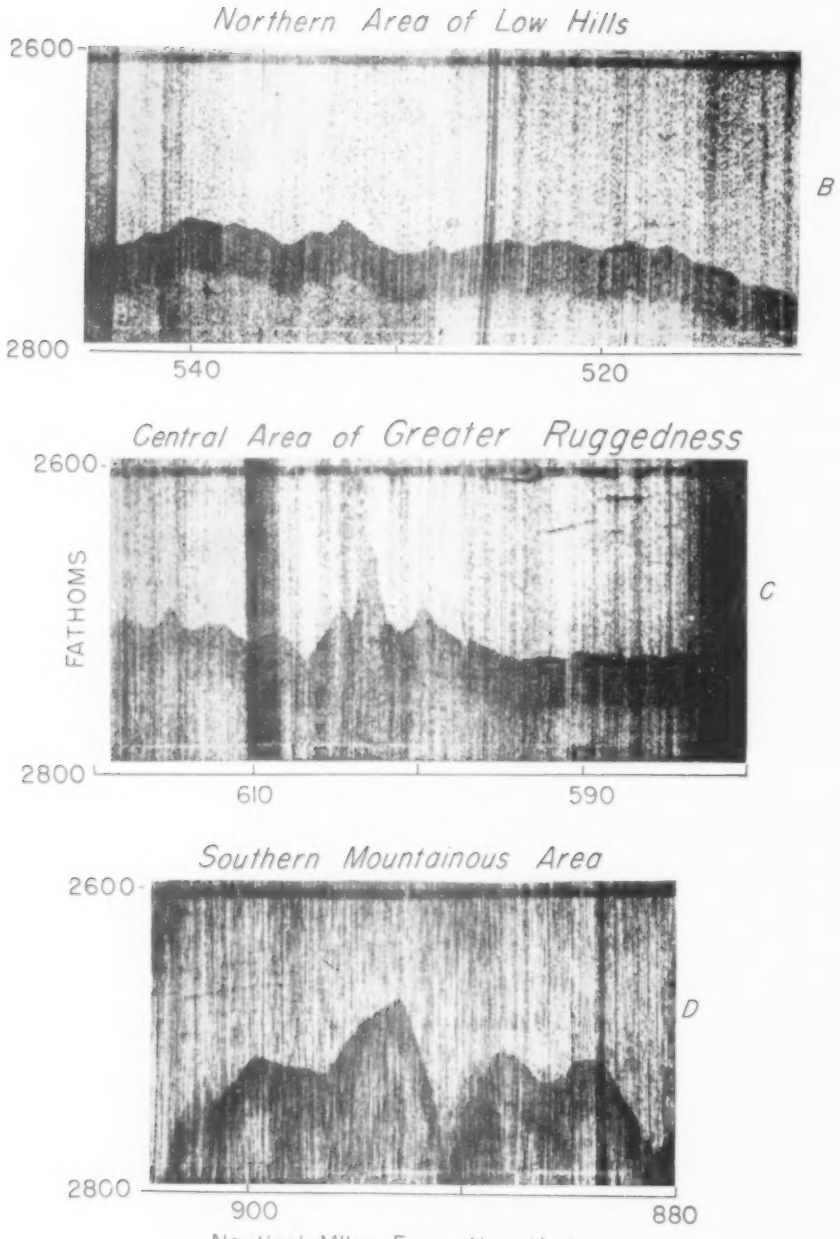

Fig 8. Records from the Bermuda Rise.
Profile B. Northern area of low hills.
Profile C. Central area of greater ruggedness.
Profile D. Southern mountainous area.

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necessary improvement. Some of these details of construction, indicated by the first tests, were effected by the time of the second sea tests from April 13 to April 19 aboard the Research Vessel *Vema* (Cruise 1). The addition of gating circuits decreased the amount of noise recorded, and results were greatly improved over the first trials. Subsequent improvements, providing more versatile keying and gating, have allowed clear, sharp records of all but the most rugged deep topography while steaming at full speed.

A typical record is shown in Fig. 5. The standard facsimile recording paper in 12 x 18¾in. sheets is grasped along the upper edge of the record by mechanical fingers extending from the recording drum. As the drum rotates the stylus is translated from left to right covering about 11½in. in one hour. The begining of the outgoing pulse is recorded at the upper margin of the record and the reverberations are cut out by the gating circuit. Therefore the depth is read by measuring the distance from the top of the band made by the outgoing pulse to the top of the bottom echo band and then adding a multiple of 200 fathoms corresponding to the scale range in which the instrument is recording. For instance, at the right edge of the record in Fig. 5, the distance from the registration of the outgoing pulse to that to the bottom echo is 75 fathoms ; to this we add 3,000 fathoms since the depth lies in the 3,000 to 3,200 fathom range. The depth range is determined by reading the record being made on the slow drum, or by counting the number of drum revolutions between the outgoing pulse and the bottom echo. On the record illustrated in Fig. 5 the second ticks sent out by radio station WWV are recorded as a check on the constancy of the drum rotation. The lower edge of the record is not secured to the drum and the brush which is supposed to press the record to the drum was not used on the first *Vema* cruise. The result is a flaring of the recording lines from the top to the bottom of the record due to the flapping of the paper on each revolution. This effect, seen in Fig. 5 did not occur when the brush was left in place on the second *Vema* cruise. The Loran receiver was located immediately next to the echo-sounder in the chart room of the *Vema* and considerable pick-up is noticed on the early records (Fig. 8) in the form of vertical grey strips corresponding to periods when the Loran set was in use.

Sounding records made with the precision depth recorder were obtained in representative topographic provinces of the North Atlantic during *Vema* Cruise 1 (Fig. 2). The Atlantic Ocean is divided into two main basins lying on either side of the Mid-Atlantic Ridge. These two main basins have been further divided into a series of smaller basins. The broad basin west of the Mid-Atlantic Ridge in the North Atlantic has been named the North America Basin. Lying approximately in the center of this is the Bermuda Rise, a 300,000-square-mile area of undulating to moderately rough topography which rises about the surrounding abyssal plains and culminates in the pedestal of the islands of Bermuda. The abyssal plains are remarkably smooth, gently sloping surfaces which occupy the deepest portion of the ocean basins (excluding for the moment the trenches). To the northwest the abyssal plain gives way to the continental rise which gently rises from the abyssal plains to the foot of the relatively steep continental slope. South and southwest of the abyssal plains lies a 100-mile-wide ridge, here called the Outer Ridge, which is located outside of the Puerto Rico Trench and the Blake-Bahama basin. The

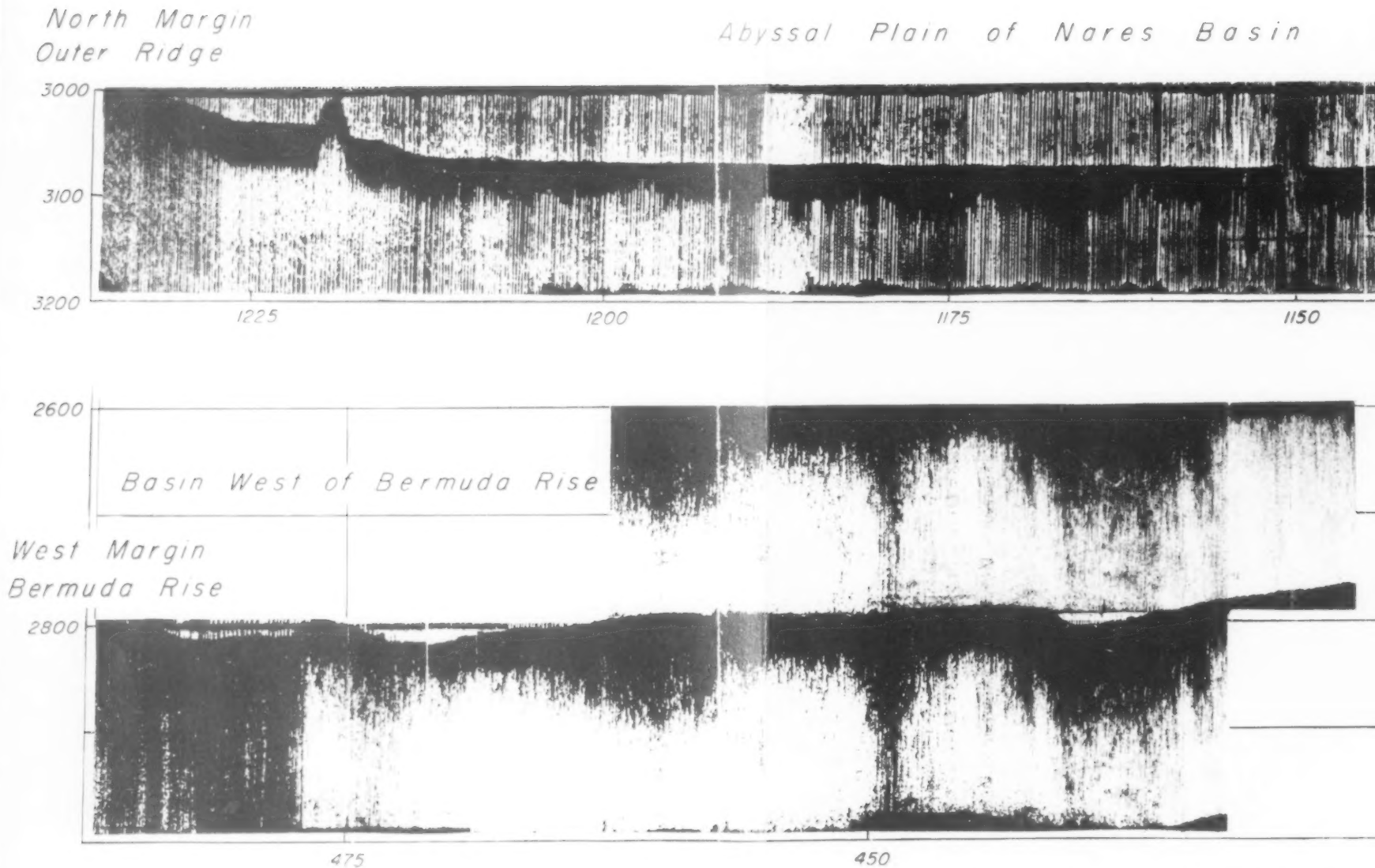
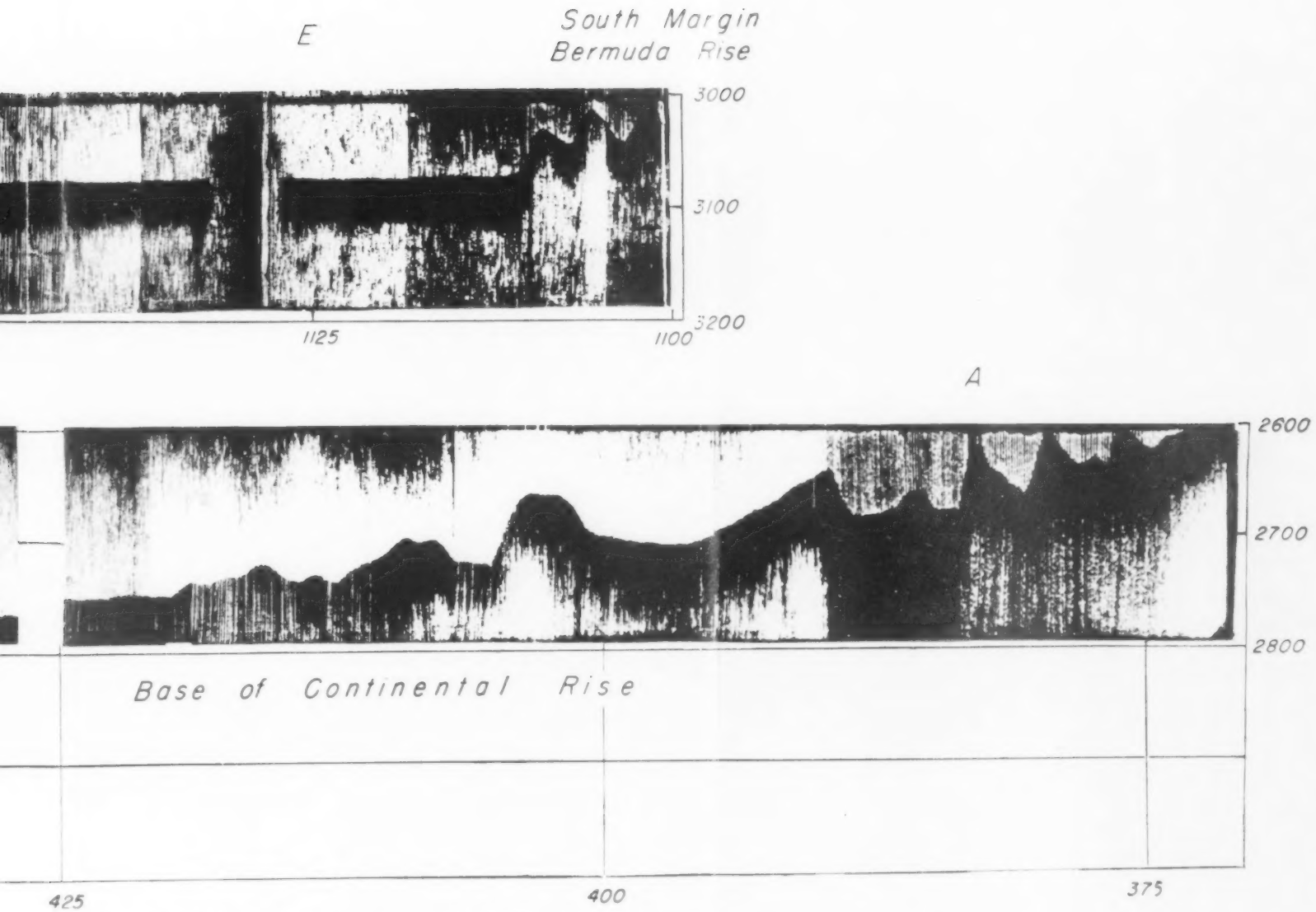


Fig. 6. Profiles constructed by piecing together copies of the depth records : Profile E. Nares Basin al



sin abyssal plain. Profile A. Basin west of Bermuda and the base of the Continental Rise.

deepest portion of the Atlantic Ocean is the Puerto Rico Trench between the island of Puerto Rico and the Outer Ridge.

Although no far-reaching geologic conclusions could be reached from one line of soundings the exceptional detail and accuracy of these records gives great promise for future explorations.

The abyssal plains shown in Fig. 2 were first delineated by a score of crossings made by the 'Atlantis' using a NMC-1 echo sounder. Where the *Vema* crossed the abyssal plain south of the Bermuda Rise (mile 1,110 to 1,200 ; Fig. 2 and Fig. 6 Profile E), the maximum depth is 3,076 fathoms (uncorrected).* The northern three-fourths of this crossing of the abyssal plain (mile 1,110 to 1,190) in nearly level along the sounding line, varying between 3,074 and 3,076 fathoms. From mile 1,190 to mile 1,210 the bottom gently rises from 3,074 fathoms to 3,067 fathoms.

Older records show the abyssal plain in this region to have a gradient down to the east-northeast of about 1 foot per mile. However, the lack of precision in the older sounders left serious doubts as to the small scale irregularities in the plain and to the absolute depth. We know now that the bottom is flat with variations of no more than 2 fathoms, and that along a north-south line the northern three-fourths of the plain is level. Near mile 1,130 and mile 1,150 two small seamounts abruptly rise from the plain.

From mile 425 to mile 490 (Fig, 2 and Fig. 6 Profile A) at the deepest portion of the profile between New York and the Bermuda Rise there are three depressions about 5 miles wide and 10 fathoms deep near mile 440, 470 and 485. These depressions may be submarine canyons which run south into the abyssal plain west of Bermuda.

The abyssal plains are thought to have originated through the ponding of sediment-laden turbidity currents which in this way built up the flat floors with detrital silts obtained from the continents. Studies of cores and topography had revealed the interesting relationship between deep sea sands and grey clays in the abyssal plains and the ends of submarine canyons (ERICSON, EWING and HEEZEN 1952). A study of the exact relationships is now possible and further surveys are planned making use of the new instrument.

In 1949 HERSEY, using the *Atlantis* and *Caryn*, surveyed in reconnaissance fashion the Puerto Rico Trench north of the island of Puerto Rico. The Trench was found to have a flat floor at approximately 4,350 fathoms. In 1951, EWING and HEEZEN, using the same vessels, extended the survey and obtained two sediment cores from the flat floor (ERICSON, EWING and HEEZEN 1952). These sediment cores, containing beds of graded shallow water material, were taken only a few miles from the profile recorded by the *Vema* (Fig. 7). The plain at this longitude is 8 miles wide and divided into two parts by a mile-wide 20 fathom hill or ridge. The northern half is nearly level at 4,338 fathoms but the southern half slopes southward from 4,342 fathoms to 4,345 fathoms. It has been suggested by HEEZEN, EWING and ERICSON (1951) that the flat plain in the Puerto Rico Trench was formed in the same manner suggested for the abyssal plains, namely by the ponding of sediment-laden turbidity currents. EWING and WORZEL (1954) give evidence that tens of thousands of feet of sediment lie below the floor of the Puerto Rico Trench.

* It is a standard practice in submarine geology to report echo soundings at the standard velocity of 800 fathoms/sec without making corrections for the variations of sound velocity. Unless otherwise noted the depths given in this paper are uncorrected. All distances are given in nautical miles.

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The slope of the southern half of the Trench floor resembles the Dominican Trench south of Puerto Rico in that the floors of both trenches slope toward the steep flanks of the island of Puerto Rico. This might be construed as evidence that recent relative subsidence of the island of Puerto Rico had tilted the originally flat floors of these trenches.

The Bermuda Rise is characterized by undulating to moderately rough topography. Fig. 8 Profile B is a profile from the northern part of the Bermuda Rise illustrating the characteristic undulating bottom with features of less than 10 fathom amplitude and 2 miles length. Fig. 8 Profile C illustrates a slightly rougher place 35 miles south of that shown by Profile B where the amplitude of the relief is over 20 fathoms, and Fig. 8 Profile D illustrates the southern mountainous area of the Bermuda Rise where the amplitude of the relief exceeds 40 fathoms. The southern area becomes rougher than that illustrated in the plate but the records do not lend themselves to illustration. It has been suggested that the contrast between the flat floors of the abyssal plains and the irregular topography of the Bermuda Rise has resulted at least in part from a different sedimentary history. HEEZEN, EWING and ERICSON (1951) suggest that the roughness presently seen on the Bermuda Rise may have also formerly existed in the part of the ocean now occupied by the abyssal plains. While the sediments from turbidity currents were forming the abyssal plains and burying the topography, the sediment settling one grain at a time from the surface water covered the topography of the Bermuda Rise but preserved it.

The base of the continental rise as shown in Fig. 6 Profile A characterized by hills and valleys about 50 fathoms deep and 5 miles wide. If these were surveyed on a zig-zag course they would probably turn out to be submarine canyons which indent the lower part of the continental rise.

CONCLUSIONS

The introduction of highly accurate facsimile recording equipment coupled to an efficient electronic echo-sounder has produced an instrument for measuring ocean depth with an accuracy of better than one fathom in 3,000 fathoms, excluding uncertainty in the speed of sound in sea water and the effect of slope. This instrumental system has substantially reduced timing errors in echo-sounding. Its high resolution permits the accurate recording of the details of ocean bottom morphology, and consequently provides a guide for the efficient utilization of deep sea instruments such as corers, dredges and cameras.

It is anticipated that further development of the echo-sounding equipment will provide new types of data on bottom and sub-bottom morphology and reflection efficiency, the scattering layers, and waves and tides in the deep ocean. This line of development appears particularly promising since the additional data can be obtained with essentially the existing technique and with no additional expenditure of sea time.

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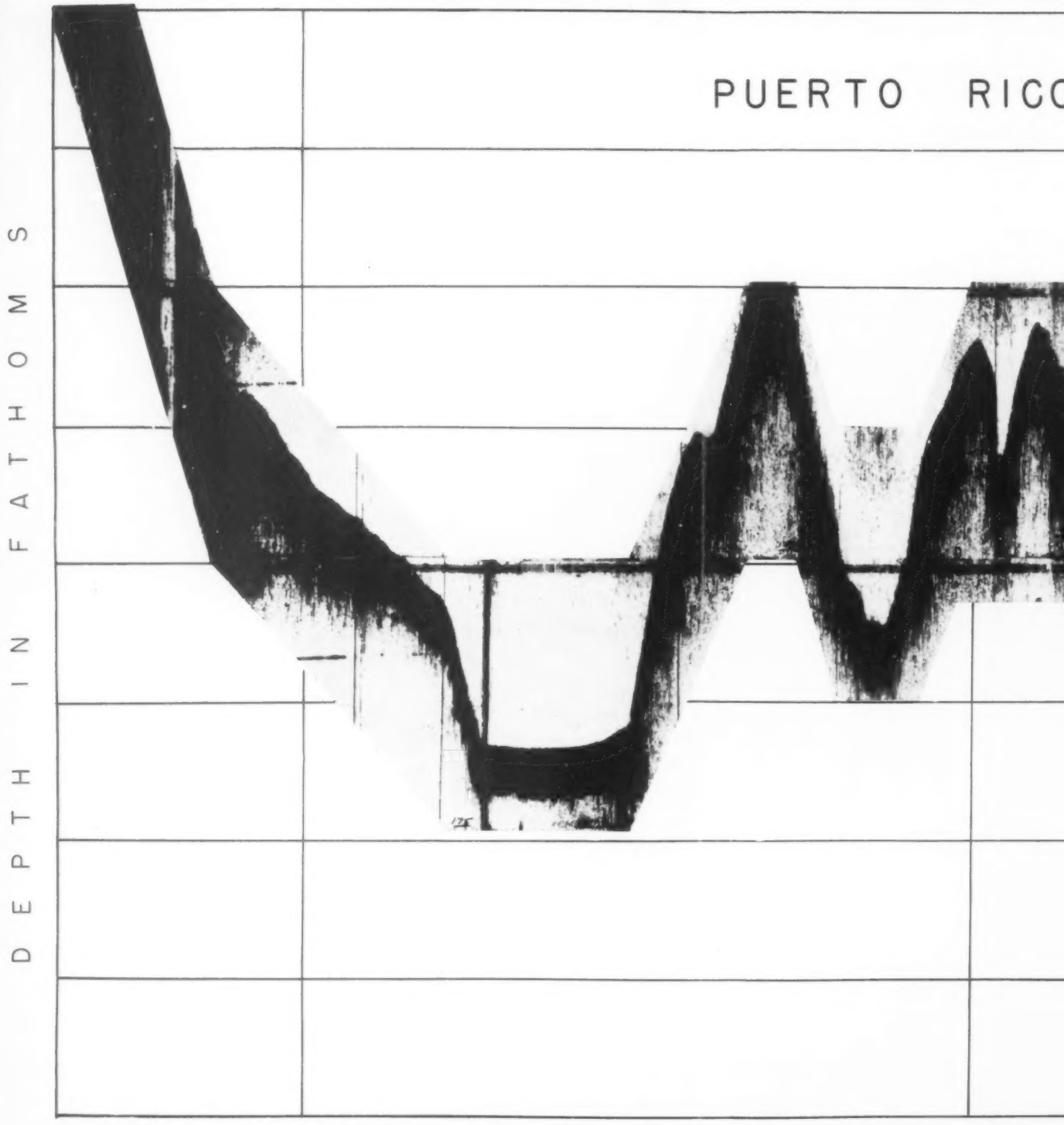
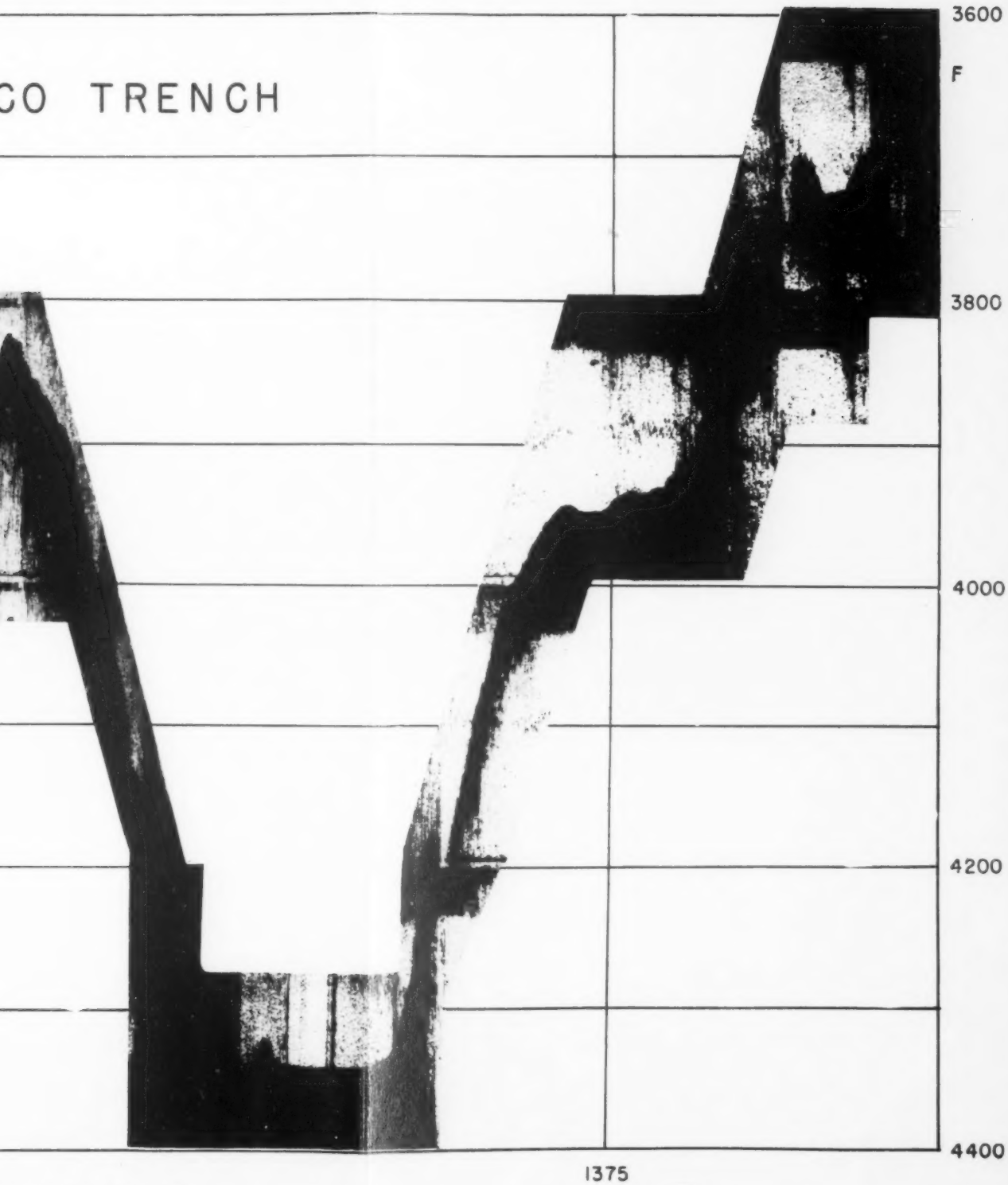


Fig. 7. Profile F. The Puerto



Puerto Rico Trench.

The equipment was constructed and assembled at the Columbia University Geophysical Field Station in Bermuda with the assistance of W. BECKMANN, F. WATLINGTON and R. FOX. J. SHONNARD and other members of the Times Facsimile Corporation contributed invaluable advice and cooperation.

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Lamont Geological Observatory, Contribution No. 103.

Lamont Geological Observatory, Columbia University.

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Notes on the Peruvian coastal current. 1. An introduction to the ecology of Pisco Bay[1]

MARY SEARS

Summary—Biological calamities of the Peruvian Coastal Current have long been associated with undue warming of the surface water. These high water temperatures have most frequently been attributed to an incursion of fresher water from the north (" El Niño "). More recently they have also been ascribed to the intrusion of wedges of saltier, warm offshore water and even to the discharge from local streams. Re-examination of the warming processes in Pisco Bay indicates that solar radiation probably accounts for a large proportion of the high temperatures observed there. Such warming can occur whenever upwelling, the only effective source of cooling, ceases for any appreciable period.

From available evidence, there appears to be an annual temperature range of about 7°C. Salinities of the current as a whole do not normally vary by as much as 2‰ whether the water be derived from upwelling, from offshore or from " El Niño." The ranges of these characteristics are much more limited than in some coastal waters and about the same as for others. The actual temperature limits are very nearly the same as for the cycle in the Mediterranean.

Consequently, before the relationship between temperature and the recurrent biological disasters can be understood, it is suggested that two peculiarities of the area should be studied in detail: (1) the process of upwelling which provides nutrient salts for the growth of phytoplankton and (2) the effect, if any, of that fraction of the birds' excreta dropped in the water on the nutrient cycle and on the character of the phytoplankton.

INTRODUCTION

THE economic importance and abundance of the guano-producing birds have long focused attention on the peculiarly rich environment provided by the inshore waters of the Peruvian Coastal Current. Despite this, remarkably little is known of the seasonal or annual cycle of events which support such enormous populations there, because previous studies have been mostly incidental to other work. Thus, there are a few widely-spaced oceanographic stations forming part of more extensive surveys elsewhere[2] and surface observations from vessels traversing the area.[3] Time and facilities precluded detailed hydrographic and biological surveys from most fisheries programmes.[4]

More spectacular and more disturbing to the economy, however, are the recurrent periods when the water temperatures rise suddenly and the birds die of starvation by the thousands. Such events have most often been attributed to the encroachment of warm water from the north (" El Niño "). This is accompanied by torrential rains and northerly rather than southerly winds in northern Peru (MURPHY, 1936; SCHOTT, 1931; ZORELL, 1928). In the Pisco area, on the other hand, there is shift in the winds from southeast to southwest (VOGT, 1942). During such periods, the anchovies are likely to disappear and the guano birds then desert their nests in search

1 Contribution No. 671 of the Woods Hole Oceanographic Institution.

2 AGASSIZ, 1906; Discovery Committee, 1949; FLEMING, *et al.*, 1945; FUNDER, 1916; GUNTHER, 1936, 1936a; SVERDRUP, 1930, 1931; Scripps Institution of Oceanography, 1952; WOOSTER, 1952.

3 COKER, 1918; Deutschen Seewarte, 1930; MURPHY, 1923, 1925, 1926, 1936; SCHOTT, 1931, 1932, 1952; SCHWEIGGER, 1942, 1942a, 1943, 1947, 1949, 1951, 1953; ZORELL, 1928.

4 BINI, 1952; COKER, 1908, 1908a, 1908b, 1908c; FIEDLER, JARVIS and LOBELL, 1943; LANDA, 1953; ROJAS, 1953.

of food. Some die of starvation and others migrate to Chile. " Red water " is also frequently reported as a consequence of " El Niño." This may cause an acrid stench (cf., BRONGERSMA-SANDERS, 1948; WOODCOCK, 1948). Fish and large invertebrates subsequently die or are found in a moribund condition on the beaches. These " crash " periods have come to be expected at intervals of seven years (i.e., 1911, 1918, 1925, 1932, 1939 and 1941): some (1891, 1925, 1953) have been more severe than others. Various phases of these catastrophies have been described,[5] but there are few published data, other than surface temperatures. In many instances, these do not sufficiently identify the source of a given water mass.

During studies of the guano-producing birds in Peru (VOGT, 1942), it was evident that the birds' lives were so dependent on sea conditions, especially on the abundance of anchovies, that a preliminary oceanographic and biological survey of Pisco Bay was made during the latter part of 1941. Surface and subsurface temperatures were observed at weekly intervals over an area of roughly 400 square miles (Fig. 1). Water samples for salinity determinations[6] were obtained, if possible, when occupying a station for the first time. These were the first subsurface observations in the littoral zone off the coast of Peru to be taken at close intervals in time and space and also under more or less " normal " conditions.

On two occasions, temperature and salinity data, as well as plankton samples were collected to the north and offshore west of Chincha Norte for a distance of about 125 miles for comparison with earlier observations (Footnote 3). Temperatures were also recorded and phytoplankton samples gathered each morning in the immediate vicinity of Chincha Norte. In addition, anchovies were brought out to the island several days each week by local fishermen.

The survey in Pisco Bay was supplemented by a similar one in the waters off Cabo Blanco in January 1942.

STATEMENT OF THE PROBLEM

Anchovies are the chief food of the guano-producing birds and disappearance of the fish means starvation for the birds (VOGT, 1942). Consequently, it is important to learn the circumstances under which the fish vanish from the surface of the Peruvian coastal waters. Two hypotheses as to where the fish disappear during the " crash " years have been proposed and both assume that high temperatures are directly responsible. One is that the anchovies migrate southward (VOGT, 1942) and this is in keeping with the idea that the " crash " years result from an unusual invasion of warm water (" El Niño ") from the north. The other (DEL SOLAR, 1942) suggests that the schools of anchovies move offshore into cool deep water. This suggestion is based on the fact that the tunas which invade the coastal areas at such times have preyed upon anchovies. There is little or no precise evidence to prove the validity of either proposal.

Some (SCHWEIGGER, 1943, p. 37) believe that the Peruvian anchovy feeds primarily on copepods and that they therefore follow the latter[7] into deeper water during

5 CURRIE, 1953a; JAMES, 1953; RAHM, 1937; SHEPPARD, 1931; STIGLICH, 1925; WILSON-BARKER, 1931, in addition to those cited in the text above.

6 Salinity titrations were carried out by members of the technical staff at the Woods Hole Oceanographic Institution. Because the method is not reliable, the salinities determined by hydrometer readings are not included in the discussion.

7 CLARKE, 1933, 1934, 1934a; GARDINER, 1933; HANSEN, 1951; JOHNSON, 1942; NICHOLLS, 1934; ROSE, 1925; RUSSELL, 1925, 1926, 1927, 1927a, 1928, 1928a.

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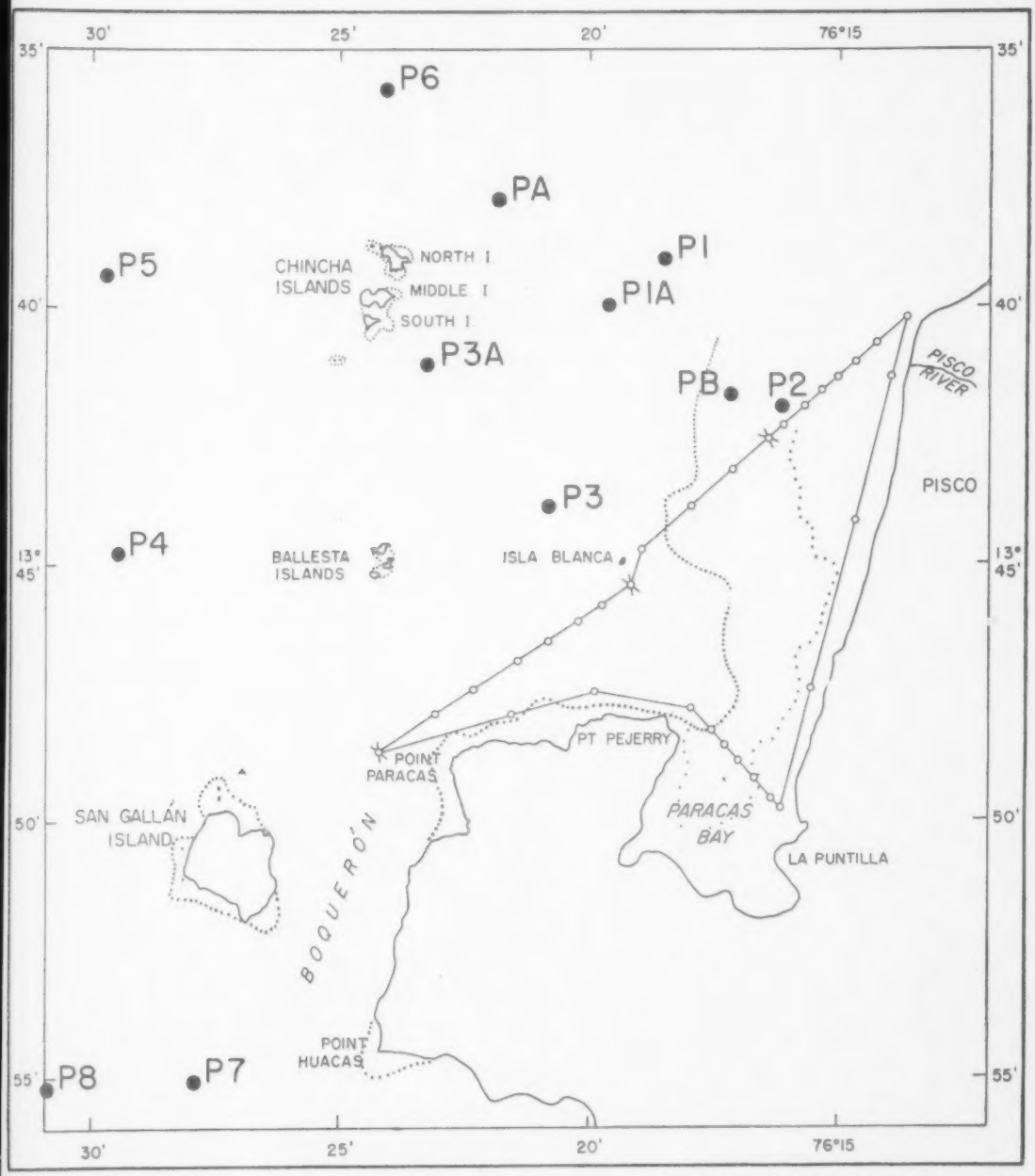

Fig. 1. Place-name chart of Pisco Bay and vicinity showing position of stations listed in Table 2, Section A. The positions of the stations in Fig. 4 are also plotted and those with the symbol ⊠ indicate stations where subsurface temperatures were taken at 10 and 20 metres.

the day. There are a few observations which seem to indicate that such a diurnal migration of anchovies may take place when the water is warmer than 20°C (HUTCHINSON, 1950). However, other than these records such evidence as we have indicates that this is not usually the case. During the " El Niño " period of 1953, schools of anchovies were reported at the surface in the general vicinity of Lobos de Afuera in northern Peru in water temperatures of 24°C to 25°C (SCHWEIGGER, 1953). Furthermore, VOGT, (1942) points out that were such diurnal migrations responsible for the disappearance of the anchovies, they would return to the surface at night. In this event, it is probable that the pelicans, which are known to feed at night, if need be, would prey upon the anchovies then. This does not apparently happen during catastrophic periods, because the pelicans, like the cormorants and boobies, die of starvation. Also, were the anchovies preying primarily upon copepods one might suppose that this sort of migration would occur during " good " times as well. Normally, however, the anchovies are sufficiently abundant at the surface to meet the food requirements of the birds (HUTCHINSON, 1950).

Other species of anchovy are reported to feed on phytoplankton at least for portions of the year[8] and there is considerable evidence that the Peruvian anchovy does likewise. The presence of diatom frustules of some of the more resistant species, such as are found in the bottom mud (NEAVERSON, 1934), have been recorded in guano deposits, both ancient and modern (CANCINO, 1950; MURPHY, 1936, p. 97; personal observations). This would appear to indicate that diatoms were present in the digestive tract of fish which the birds had eaten. Furthermore, VOGT (1942) noted that the periods when the food supply of the cormorants appeared to be plentiful, as reported by the wardens, corresponded in general with periods when the water was least transparent (i.e., the phytoplankton was so abundant as to make the water murky). Examination of the stomach contents of more than 2,000 individuals indicate that the Peruvian anchovy does feed primarily on phytoplankton, especially diatoms, at least over a period of months (29 September to 19 December 1941). More recently, similar results have been obtained which extend the period from June through January and February (ROJAS, 1953).

The production of diatoms in sufficient numbers to provide for the guano birds and other predators is in large part determined by the supply of nutrient salts. These are not likely to be a limiting factor under usual conditions because the cool coastal waters which result from upwelling[9] keep their concentration high in the photic zone (GUNTHER, 1936). Therefore events in the sea which might interrupt or disrupt this cycle could account for the recurrent disasters in " crash " years.

Biological calamities of the Peruvian coast have always been associated with undue warming of the water. These high temperatures have most frequently been arttibuted to an incursion of fresher water from the north (" El Niño "). At times, however, they have been ascribed to wedges of saltier, warm offshore water approaching the coast (GUNTHER, 1936; SCHWEIGGER, 1942, pp. 71-73; VOGT, 1942) and sometimes to the effluent from local rivers such as that from the Pisco and San Juan de Chincha Rivers (SCHWEIGGER, 1942, pp. 77-80). It has also been suggested that solar radiation

[8] There are a number of papers (ANDREU y RODRÍGUEZ-RODA, 1951; DEBUEN, 1931; FAGE, 1911, 1920; MIRANDA y RIVERA, 1930) which provide background information on feeding, migrations, etc., for the Mediterranean anchovy.

[9] GUNTHER, 1936; SCHOTT, 1931, 1932; SVERDRUP, 1930, 1931. Also, cf., CURRIE, 1953, for the Benguela Current and SVERDRUP and FLEMING, 1941, and California, Marine Research Committee, 1953, for the California coast.

may be significant in local warming (SCHWEIGGER, 1942, p. 77). Whether the effect of high temperatures be a direct one or an indirect one due to differences in the concentration of nutrient salts of the water masses concerned, the reasons for such temperature increases are important in understanding the ecological relationships of the Peruvian coastal waters. Consequently, an attempt is made here to distinguish the relative importance of the several types of warming.

WARMING IN PISCO BAY

Warm temperatures due to an incursion of " El Niño " are said to extend at times as far south as Pisco Bay. In 1925, there were a sufficient number of surface temperatures recorded from vessels traversing the waters of the Peruvian coast to document a progressive southward advance of temperature increases as far south as Pisco Bay (SCHOTT, 1931, pp. 211-212; MURPHY, 1926; ZORELL, 1928). These persisted in Pisco Bay from 15 to 24 March. Subsequently, it has been learned that surface temperatures as high as 20°C to 22°C are common in the Bay and even as high as 24°C to 25°C are not infrequent in February, March and possibly even in April. These temperatures are not considered to have resulted from an incursion of " El Niño " (SCHWEIGGER, 1942; VOGT, 1942). More recently (1953), when " El Niño " extended only as far south as Paita, warming *in situ* took place to the south apparently due to a cessation of upwelling (AVILA, 1953). Since this was the worst " El Niño " year since 1925, the possibility is raised that a similar situation existed in 1925 and that " El Niño " was not responsible for the temperature increase in Pisco Bay that year.

To verify the characteristics of " El Niño " water, simultaneous observations of temperature and salinity at several subsurface depths were made off Cabo Blanco (4°16′ S, 81°15′ W) in January 1942, the season when " El Niño " might be expected there. The resulting T-S diagram (Fig. 2) indicates that in the upper 25 metres, the temperatures were as high (21°C to 23°C) or a little higher than off Pisco, but the salinities were consistently lower than might be expected for these temperatures in the Pisco Bay area (Fig. 2; cf., Tables 1 and 2). The layer of fresher water was 3 to 10 metres deep within about 1·5 miles from the beach and 25 metres deep at about 30 miles offshore. Below 50 metres, the water had essentially the same characteristics as in the vicinity of Pisco Bay. At intermediate depths, the water appeared to be a mixture of the two.

Fresher water similar to that found off Cabo Blanco in January 1942 (Fig. 2) was found extending northward from Lobitos in September 1927 and November 1929 (Deutschen Seewarte, 1930), to the north and west in July and August 1931 (DISCOVERY COMMITTEE, 1949, Sta. Nos. 708-712, 715-719), and also as far south as 8°51′ S, 79°31′ W in March 1931 (SCHOTT, 1931, p. 245). The latter, it should be noted, was farther south than in 1953 and yet there is no mention in the scientific literature, insofar as I am aware, to indicate that 1931 was a " crash " year. Water of this sort was not found in the Pisco area during the latter part of 1941 or in 1953 (AVILA, 1953; POSNER, 1953).[10] Thus, at times, situations off the Peruvian coast, formerly attributed to " El Niño " are not of this origin as already recognised by GUNTHER (1936), SCHWEIGGER (1942), and VOGT (1942).

[10]SCHWEIGGER (1953) has entered some salinity data on charts, but without giving the temperatures taken at the same time. Insofar as one can judge by interpolation of the temperatures, the salinity values given on Map Nos. 3, 4 and 5 appear to be in agreement with other reports. Those on Map Nos. 1 and 2 appear to indicate that " El Niño " water was present.

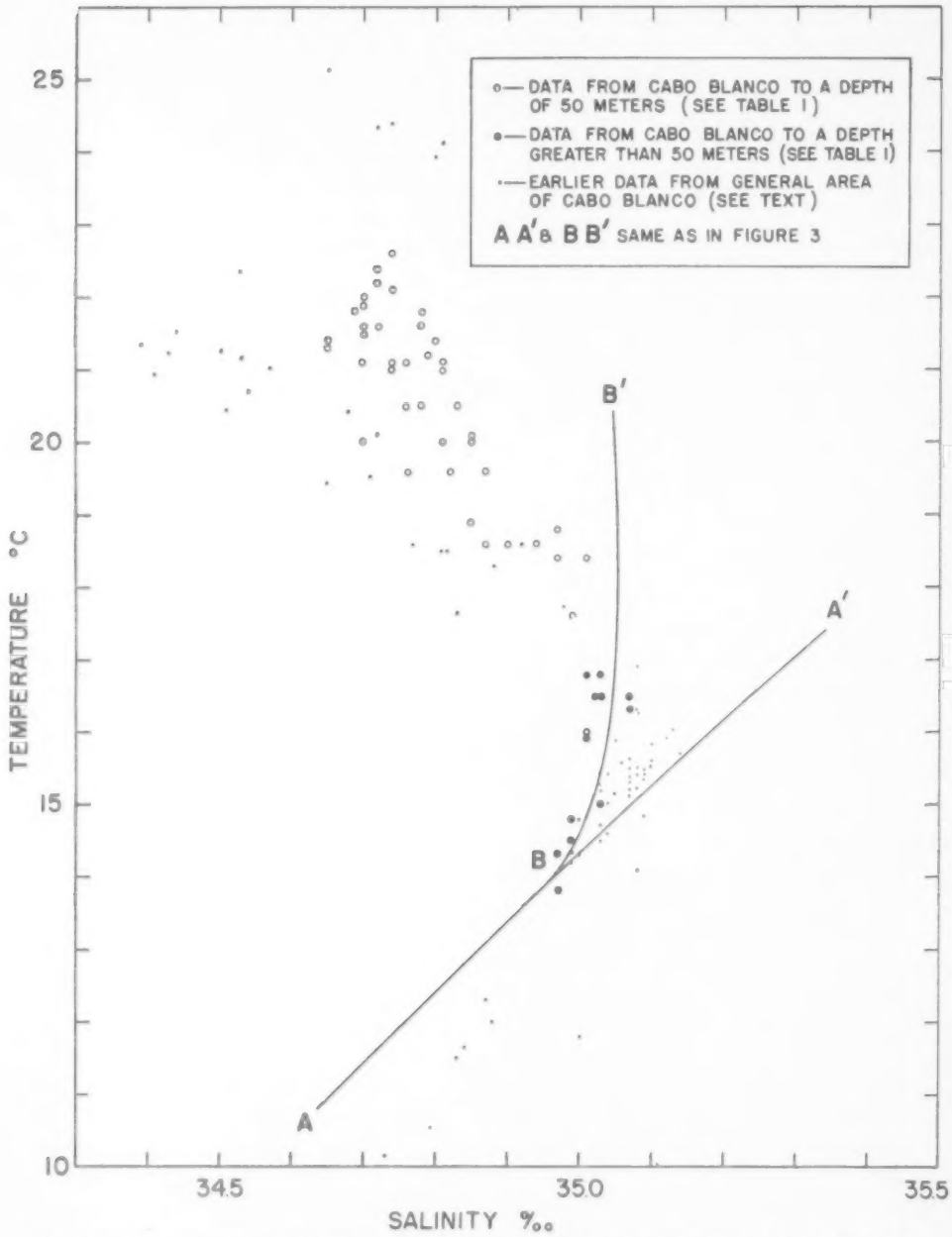

Fig. 2. T-S diagram comparing characteristics of the water in the Cabo Blanco area with earlier records of similar origin.

Intrusions of tongues of warm offshore water, first mentioned by GUNTHER (1936) have been considered as a source of higher temperatures in Pisco Bay (GUNTHER, 1936, p. 194; SCHWEIGGER, 1942, pp. 71-73; VOGT, 1942) but these observations were not accompanied by salinity determinations to prove their offshore origin. To ascertain whether offshore water has been found in the general vicinity of Pisco Bay, the available temperature and salinity data from pertinent depths out to 85° W, and from 5°S to 17°S were plotted on a conventional T-S diagram[11] for comparison with those from the *Carnegie* in the same latitudes, between 90°W and 115°W (*Carnegie* Sta. Nos. 46, 47, 75, 76, 77, 78, 79). The latter are situated where a maximum salinity obtains (Fig. 3, AA′) and may be considered as characteristic of the water masses from the Eastern South Pacific as a whole.[12] The great majority of the points fall within relatively narrow limits for depths greater than 200 metres (Fig. 3), but at lesser depths there is a marked scattering at most stations between the Peruvian coast and 95°W. The scatter is accentuated when curves are plotted for individual stations. These curves, because of the uniformity in salinity in the upper layers, are indicative of upwelling (as will be mentioned again in another connection). Both presentations indicate that the water is distinctly fresher and usually somewhat cooler in the shallower layers than is characteristic for the Eastern South Pacific as a whole (Fig. 3, AA′). These data suggest, then, that the relatively warm saline water characteristic of the Eastern South Pacific does not ordinarily occur within several hundred miles of the South American coast. The *William Scoresby* observations for depths down to between 30 and 50 metres at Sta. Nos. 667, 668, 670, 671, 674, 682, 683, 686, 730, 731 and 734, as well as those taken from the *Oldenberg* (DEUTSCHEN SEEWARTE, 1930) at the surface west of 80°W in the sector under consideration are the exceptions. The data from the shallow depths at these stations fall close to AA′ on the T-S diagram (Fig. 3), indicating an offshore origin. Only three, however, are on the continental shelf and none are within about twenty miles of shore. Although such water was found about 112 miles to the westward at the time of our observations, it was not found in the Pisco Bay area. It therefore remains to be learned whether warm offshore water with salinities higher than about 35·3‰ ever significantly affects the Pisco area.[13]

Within Pisco Bay proper (Fig. 3), all temperatures and salinity data when plotted on a T-S diagram (Table 2; FUNDER, 1916) fall along BB′, almost at right angles to the abscissa. The salinity does not vary by more than about 0·15‰ between the greatest subsurface depth on the continental shelf and the surface even although the temperatures vary from 13·8°C to 20·0°C, the extremes found in the area at the time of our observations. Water of 13°C to 14°C, the minimal recorded in the Bay, is usually found with salinities of 34·96‰ to 35·06‰ at depths of 150 to 200 metres, perhaps a little deeper (250-300 metres) at stations off the continental shelf

[11]Such a wide latitudinal span was included because so few observations have been made within the immediate offing of Pisco Bay. Since the scatter at shallower depths was as marked when only the few data between 12°S and 14°S were used, it does not appear that for purposes of the present analysis any undue inconsistencies were introduced.

[12]There seems to be some precedent for such a procedure (REDFIELD, 1950; SVERDRUP, JOHNSON and FLEMING, 1942, Fig. 194; FLEMING, *et al.*, 1945, Figs. 205, Sta. Nos. 78-89; SVERDRUP, *et al.*, 1944, pp. 126-127, Fig. 14).

[13]SCHWEIGGER (1947, p. 60) reports salinities of 35·25‰ but corresponding temperatures and localities are not given. Although this value is relatively high for recently upwelled water, it has been recorded at temperatures between 13° and 14°C. It therefore is not possible to determine the source of a water mass with such salinity values without more data.

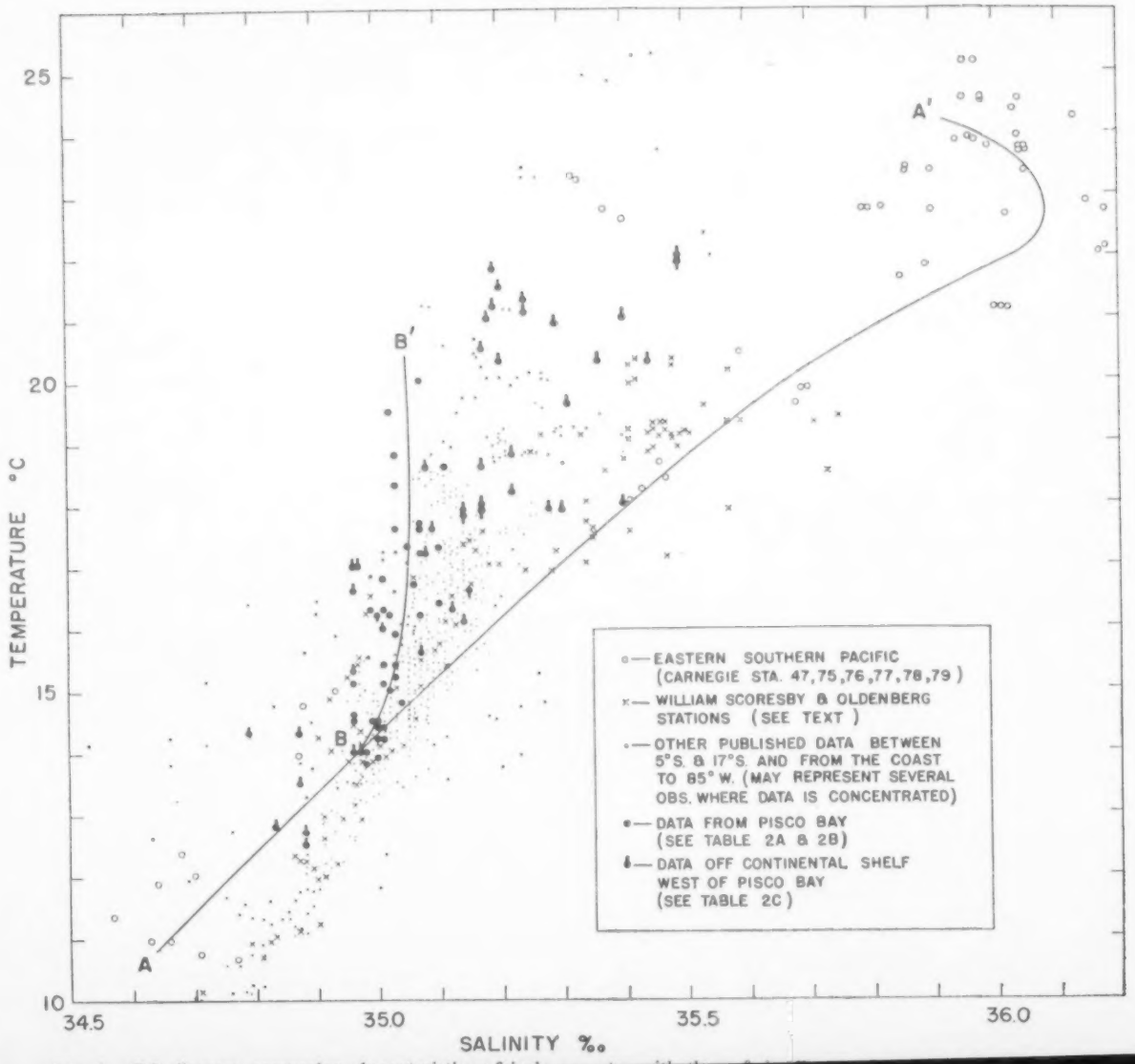

Fig. 3. T-S diagram comparing characteristics of [illegible]

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as already reported by GUNTHER (1936) and SVERDRUP (1930). Our stations to the west of Chincha Norte indicate that even within 100 miles of the island these temperatures may be found at depths of 100 to 200 metres. In short, the uniformity of the salinities in Pisco Bay may be accounted for by upwelling from some subsurface layer and the higher temperatures in all probability by solar warming *in situ*, as will be shown below.

It is possible to estimate roughly whether solar warming in the absence of marked upwelling could produce the higher temperatures recorded in 1941. In these computations, it is necessary to simplify the conditions which probably existed in the bay by neglecting currents and horizontal mixing. On the other hand, a certain amount of downward mixing must be assumed to account for observed temperatures at a station close to Chincha Norte where weekly temperatures at 10-metre intervals down to 50 metres were recorded for the latter part of 1940 and much of 1941 (Table 3). Averages for this water column reveal a noticeable warming as early as 29 December 1940 (Table 3), a warming which continued until mid-March 1941. Thereafter, it cooled gradually until mid-June, when the observations were suspended. The greatest increase between any two sets of observations in the average temperature for the 50-metre column was 2·1°C (Table 3) between 19 January and 16 February 1941. To raise the temperature of this column of water by 2°C requires 10,000 gram calories per square centimetre of sea surface or 358 gram calories per square centimetre per day. For the season and latitude under consideration, it is estimated that the average radiation from sun and sky amounts to at least 432 to 648 gram calories per square centimetre per day (SVERDRUP, JOHNSON and FLEMING, 1942, Table 25). If it is assumed that reflection from the water surface is negligible (SVERDRUP, JOHNSON and FLEMING, 1942, Table 26) and that all the radiation enters the water it would take between fifteen and twenty-three days to produce the observed warming. Consequently, only 55% to 82% of the heat available appears to have been required to produce the observed temperature increase.

The most extreme temperatures recorded within the Bay can also be accounted for in this way. The higher temperatures appear to emanante from the inner part of the Bay off Pisco (Fig. 4; SCHWEIGGER, 1942) in an area (Fig. 1) which roughly coincides with depths of less than 20 metres. The same number of calories entering through the surface will increase the average temperature of shallow waters more than that of deep. Thus, during the period required to warm the 50-metre column close to Chincha Norte by 2°C, the temperature off Pisco would have risen by perhaps 5°C and in Paracas Bay by 10°C. This means if we assume that the water throughout the Bay averaged roughly 17·4°C at the start and warmed to 19·4°C at Chincha Norte the temperature off Pisco might have risen to 22·4°C and in Paracas Bay to 27·4°C during the same period. Except for the latter, similar surface temperatures have frequently been reported (SCHWEIGGER, 1942; VOGT, 1942; AVILA, 1949, 1950. See also Table 2).

Thus far, it has been assumed that a certain amount of heat was mixed downward through wave action or some such turbulent process, but during periods of calm, a large percentage of the warming would take place in the upper metre of the water mass (SVERDRUP, JOHNSON and FLEMING, 1942, Table 28). Under these conditions in midsummer (January-February), one could expect for each day of calm to find an increase of 2·38°C to 5·35°C at the surface. Increases of 1·8°C to 2·4°C (SCHWEIG-

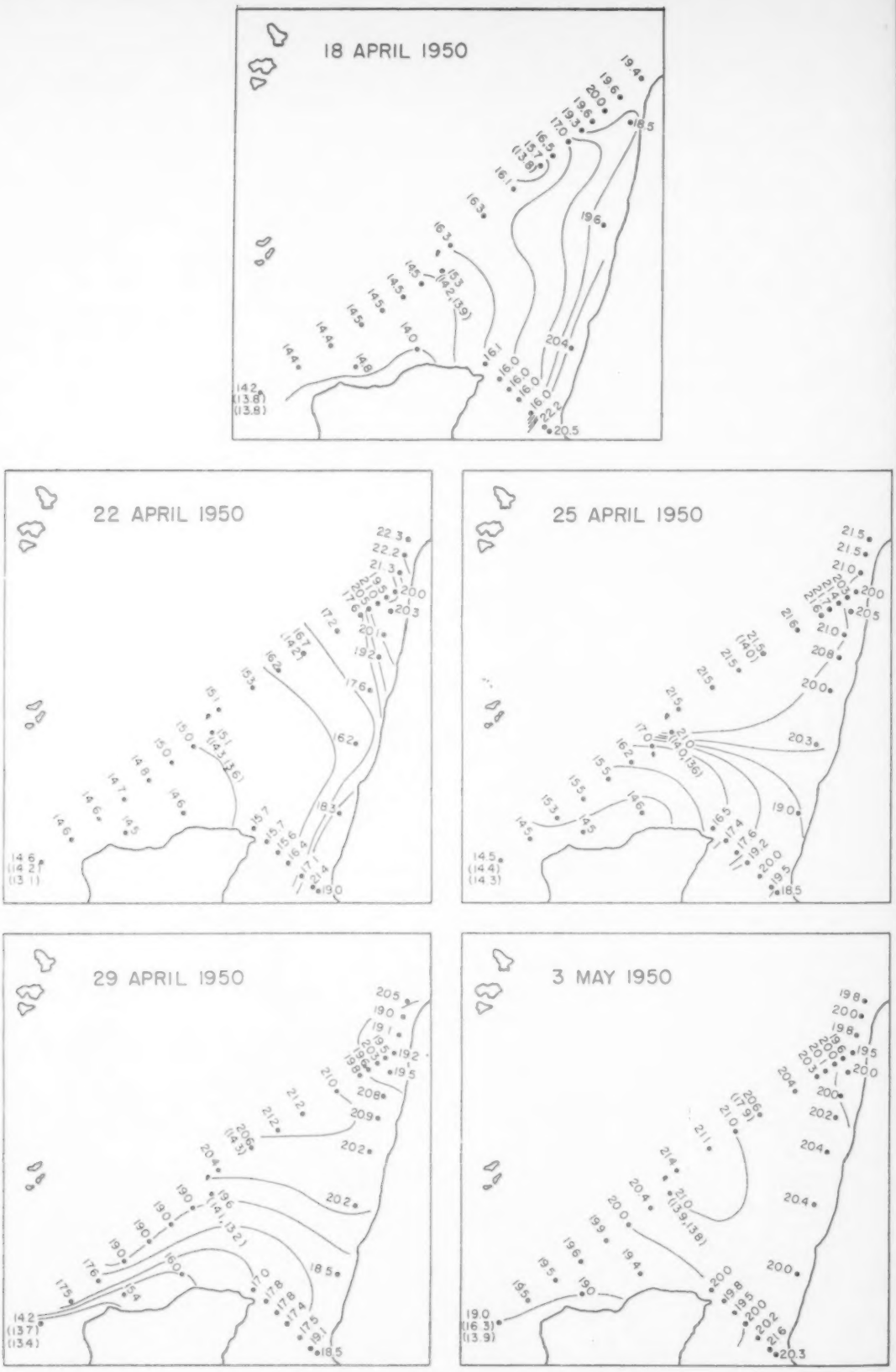

Fig. 4. Surface temperatures collected by Señor ENRIQUE AVILA. Temperatures in parentheses at 10 and 20 metres respectively.

GER, 1942, Map 22; AVILA, 1950) have actually been reported between 6 a.m. and about 2 p.m. and of 4·5°C in a twenty-four hour period at Chincha Norte (VOGT, unpublished data, January 1940).

In addition to these isolated examples, the surveys made of the inner portion of the Bay in April 1950 (AVILA, 1950) illustrate the same sort of warming over a considerable area (Fig. 4). It may be assumed that the water in the Bay had upwelled very shortly before his surveys started, because the temperatures were 14·2°C at 10 metres and 13·9°C at 20 metres. Only the shallowest layers in the inner part of the Bay showed any significant warming (Fig. 4). With an estimated 410 to 432 gram calories per square centimetre per day in this latitude in April (SVERDRUP, JOHNSON and FLEMING, 1942, Table 25) there was enough heat to warm a layer about 10 metres deep by 1°C in about two and a half days. An increase of 1°C was actually observed off Pisco between 18 and 22 April 1950 (Fig. 4). Similarly, it might be expected that the observed increase of 4·8°C between 22 and 25 April was restricted to a shallower depth indicating that there had been little mixing. The slight decrease at the surface between 29 April and 3 May does not necessarily indicate an intrusion of cold water, but rather a mixing down to at least 10 metres (Fig. 4), since the average temperature had increased to that depth by 1·5°C (cf., FREEMAN, 1953). At the northerly entrance to the Boquerón, however, the increase in temperature is nearly twice as great (i.e., 3·5°C) as could be accounted for by solar radiation alone. In situations such as this, one can only assume in the absence of any precise information that local water movements may in some way account for the increase. In any event, the area with water as warm as 15°C to 21°C or more was progressively expanding and moving toward the Boquerón between 18 April and 3 May (Fig. 4).

It also appears more reasonable to explain the existence of warm water in the inner part of the Bay as resulting from water warming over shallow bottom rather than from the river outflows. Recent studies[14] of rivers with a discharge several hundred times greater than those entering Pisco Bay have provided a convenient method for computing the effect of river effluent on adjacent bodies of water. It is obvious from these that the relatively small streams entering Pisco Bay could only have an infinitesimal effect on the salinity of the area.[15] The same conclusion could

[14]FORD, 1949; KETCHUM, 1950, 1951, 1951a; KETCHUM, REDFIELD and AYERS, 1950.

[15]The fraction of fresh water (F) in any sample required to reduce the salinity observed at the time of my survey (i.e., about 35‰ by merely one part per thousand over the surface of the Pisco Bay area is found by the following relationships (KETCHUM, REDFIELD and AYERS, 1950, p. 28):

$$F = \frac{35 - 34}{35} = \frac{1}{35} = 0{\cdot}0286.$$

The general area under consideration is roughly 400 square miles or about $14{\cdot}8 \times 10^9$ square feet. For convenience in computation, we may take into consideration only the surface layer to a depth of one foot. The volume of fresh water required to decrease the salinity by only one part per thousand is found by multiplying the fraction (F) by the volume of water in the surface layer to a depth of one foot :

$$0{\cdot}0286 \times 14{\cdot}8 \times 10^9 \text{ cubic feet}$$
$$= 423 \times 10^6 \text{ cubic feet}$$

The flow from both rivers entering the area is reported to be roughly 76,000 litres per day (SCHWEIGGER, 1942, p. 80). Therefore before enough fresh water could enter from this source to effect a change of one part per thousand in the salinity, it would take: $\frac{423 \times 10^6}{2{\cdot}63 \times 10^3} = 160{,}000$ days or more than 400 years, provided that all other processes which might tend to increase or decrease the salinity be inactive.

be reached by considering the heat contribution of the rivers. We can, therefore, dismiss the discharge from the two rivers as a means of increasing the surface temperature of Pisco Bay in any significant way, especially since the salinity normally tends to increase, not decrease, with temperature (Fig. 3).

Solar warming then can account for most of the sudden increases in temperature which have been observed in Pisco Bay from place to place and almost from hour to hour.

COOLING IN PISCO BAY

The cool water on the Peruvian coast upwells from subsurface layers with a temperature between 13°C and 14°C. (GUNTHER, 1936; SVERDRUP, 1930). Indications are that this water rises to the surface in the general vicinity of Punta Huacas south of the Boquerón (Fig. 1). The coldest water is frequently found there and extending northward into the Bay toward the Ballestas and Isla Blanca (Fig. 4). Not infrequently, surface temperatures below 15°C are found in this general vicinity (AVILA, 1949; 1950; MURPHY, 1923; SCHWEIGGER, 1942) and water of 13°C has actually been observed at the surface close to Isla Blanca. In 1941, the coldest water was somewhat warmer (between 14°C and 15°C), but nevertheless it too was found south of San Gallán at depths of 10 metres or more. Elsewhere it occurred as deep as 50 metres. In other years, as exemplified by 1950 (Fig. 4), temperatures of 14·0°C and 14·5°C occur over much of the southwestern portion of the Bay and its approaches and within 10 metres of the surface elsewhere.

As mentioned earlier, temperatures recorded in Paracas Bay are not as high as might be expected in an isolated shallow bay. The temperatures there the latter part of April 1940 (Fig. 4) indicate that the water east of Punta Pejerry was no warmer than much of Pisco Bay. On the other hand, close to La Puntilla, the morning temperatures was consistently cooler than one taken at the end of the circuit in early afternoon. It looks then as if cool water from the Boquerón flows north of the Paracas Peninsula and around Punta Pejerry into Paracas Bay. It may be that this is part of a counter clockwise circulation in the Bay, which would tend to develop as a result of the prevailing southeasterly wind.

This sort of temperature distribution means that with each pulse of upwelling, cold water surges into the Bay through the Boquerón. It is not possible to determine with existing data whether each such pulse flushes out the bay or whether the amount of water entering the Bay varies depending upon the strength of the upwelling. The cold temperatures so close to the surface in April 1950, together with the fact that most of the somewhat warmer surface temperatures observed in the Bay at that time can be accounted for by warming *in situ* of relatively short duration certainly seems to suggest that flushing may at times be practically complete.

In the computations of warming from solar radiation, mixing was considered as a mechanism for distributing heat downward from the surface. However, the Bay is not an isolated body of water as this might imply. Under somewhat different circumstances, mixing can also be a means of cooling (cf., FREEMAN, 1953). The warm temperatures observed at the surface with a sufficiently strong wind would mix with the cold water existing below 10 metres with the result that the surface temperature would be considerably reduced. Under such circumstances, surface cooling is not indicative of a new intrusion of cold water. Once again, it appears that surface temperatures are not reliable when interpreting hydrographic conditions.

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TEMPERATURES IN "CRASH" AND "NORMAL" YEARS

Surface temperatures of 20°C to 21°C or even higher occur over large portions of the Bay much of the year, in both "crash" years and "normal" ones. They are therefore not a reliable index for differentiating between them. On the other hand, subsurface temperatures may prove useful in this respect. In a "crash" year, such as 1941, the warming process is predominant, apparently through a cessation of upwelling for a more or less prolonged period. In the absence of upwelling, the water in the Bay is warmed by the sun. Through mixing the warming extends downward depressing the isotherm for 14°C to a depth of 50 metres or more and it may then remain deep for as long as six months from midsummer to midwinter (Table 3). Even in the absence of upwelling, some seasonal cooling takes place in late spring before the heavy cloud develops, a cloud which hangs over the coastal region perhaps eighty per cent of the time during the winter months (U.S. Navy Hydrographic Office, 1938). Despite this cooling, the isotherm for 14°C tends to remain deep, until upwelling again becomes active.

In a "normal" year, such as 1950, the cooling process appears to dominate except at the very surface, presumably because of repeated upwelling, possibly as often as every two or three weeks. Were upwelling more infrequent, it might be expected that the water column down to at least 50 metres would warm by about 2°C, as it did in 1941. Judging from the situation in April 1950 (Fig. 4), this does not happen, but rather the 14°C-isotherm lies within 10 to 20 metres of the surface and the temperature for the water column down to 50 metres averages close to 14·5°C rather than 18°C as in 1941. Superficial temperatures may, however, be as high as in a "crash" year following several days of calm or light winds.

ANNUAL TEMPERATURE CYCLE

One further point needs to be considered in trying to understand the hydrographic situation in Pisco Bay, namely, the annual temperature cycle. In most earlier discussions, this has not been stressed, perhaps because the significant temperature changes have always been so sudden and catastrophic. Nevertheless, such a cycle appears to exist in the surface layers, at least, for certain sectors of the coast (SCHWEIGGER, 1951; U.S. Coast and Geodetic Survey, 1948; U.S. Navy Hydrographic Office, 1938) with an average difference between summer and winter of roughly 7°C. Temperature differences of this magnitude in such low latitudes could readily be explained by the low dense cloud present nearly 80 per cent of the time during the months of July, August and September in contrast to practically clear skies from January through April (U.S. Navy Hydrographic Office, 1938). Such a cycle is revealed when surface data are averaged over a considerable number of years (SCHWEIGGER, 1951). From these, it appears that the extreme surface temperatures for any year along the Peruvian coast at least as far south as 12°S, whether in "normal" or "crash" years is usually as great as any ever recorded in Pisco Bay (SCHWEIGGER, 1951).

Some caution must be used, however, in interpreting averaged data of this sort, as the actual situation may be obscured. This has been demonstrated in studies of the Gulf Stream, for example (FUGLISTER, 1951). In a warm year, such as 1941, a year which was characterized by an almost complete absence of upwelling, the annual cycle was apparent in both surface and subsurface layers. In more usual years, such

as 1950, it seems likely that the temperature cycle for the water column as a whole will be completely obscured by upwelling, which may also keep the surface temperatures low. It might also be expected that the surface temperatures might fluctuate markedly increasing during periods of calm or light winds, but decreasing with stronger winds.

COMPARISON WITH OTHER AREAS

Temperatures of the Peruvian littoral are not as extreme as those in some temperate regions, such as along the east coast of the United States. There, for example, at the warmest season, the surface temperatures from Chesapeake Bay to Cape Cod (BIGELOW, 1933, Fig. 35) are the same or even a little higher (i.e., 23°C to 26°C) than in Pisco Bay. The winter temperatures, however, are very much lower, ranging from about 2°C to 8°C.

Likewise, in midsummer, when a marked thermocline is established, there may be a considerably greater contrast in the vertical temperature distribution off the east coast of the United States. There a pool of cool water of from 6°C to 8°C lies at depths of 40 metres or more (BIGELOW, 1933, Figs. 41-44), but the surface temperature may be as high as 25°C. Within 25 metres there may thus be a vertical temperature gradient of 16°C, a range greater than any ever recorded on the Peruvian coast.

Similarly, the salinities regularly occurring along the Peruvian coast are much more uniform than along the east coast of the United States. Ordinarily, on the coast of Peru, salinities do not vary by as much as 1‰, never by more than 2‰. To be sure, at the mouth of a stream, this might not be true, but freshening from this source, as already pointed out, is insignificant for the Coastal Current as a whole. In contrast, off the east coast of the United States, crossing the continental shelf somewhat north of Cape Hatteras, the salinities may vary between 29·96‰ to 35·9‰, a gradient of 6‰. Vertically, in as little as 20 metres, the gradient may be 2·95‰ (29·96‰ at the surface and 32·91‰ at 20 metres) (BIGELOW and SEARS, 1935, Fig. 8) and at one locality there may be an increase from 29·65‰ to 32·24‰ in a fortnight (BIGELOW and SEARS, 1935, Fig. 25). These are extreme values, but nevertheless they may be expected with some regularity over considerable areas at certain times of year.

In other areas, such as the Bay of Fundy, the annual temperature range (8·6°C to 10°C) and the annual salinity range (0·7‰ to 1·4‰) (BAILEY, MACGREGOR and HACHEY, 1954) are roughly the same as off the Peruvian coast. In the Mediterranean, the annual temperature limits (i.e., about 13°C to about 26°C) (RODRÍGUEZ-RODA, 1953) are almost identical with the most extreme temperatures of the Peruvian Coastal Current. Thus, the temperatures and salinities of the Peruvian Coastal Current are not unique nor are they extreme, a situation that appears to have been overlooked.

BIOLOGICAL CONSIDERATIONS

There are two types of biological disasters, both associated with high water temperatures and formerly considered as a consequence of "El Niño." The first is the disappearance of the anchovies. This is the cause of death from starvation among the guano birds. Warming *per se* could be responsible for this type of disaster

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despite the relatively narrow temperature limits of the Peruvian Coastal Current. A considerable number of the diatom species occurring there are also found in more temperate regions. It may be that the lower temperatures of the Current are near the upper limits of their tolerance. On the other hand, it might be that the supply of nutrient salts becomes depleted in the absence of upwelling. Thus the production of diatoms would be restricted. In either event, the anchovies would go elsewhere in search of food. These points need clarification.

The second type of disaster is associated with the appearance of " red water " (" aguaje "). There are numerous examples elsewhere that this is usually accompanied by a mass mortality of fish and larger invertebrates.[16] " Aguaje " (" red water ") has most frequently been reported as resulting from an incursion of " El Niño " (LAVALLE y GARCIA, 1918; SHEPPARD, 1931). It has also occurred in water of offshore origin (GUNTHER 1936a, pp. 57-58) and in October 1941 it was found in upwelled water between Chincha Norte and Tambo de Mora.

To illustrate the complexity of the problem, the situation existing at the time of the " aguaje " of October 1941 is recorded here in some detail. Several million odd cormorants nesting in the Ballestas were going out each day in search of food and sufficient numbers of anchovies were available to prevent a mass starvation of the birds and at times even to attract whales. One Sunday, thirteen were spouting at one time within view of Chincha Norte and schools of anchovies were breaking the surface. During this period of plenty, there are notations in my records which suggest that all was not going well in the area. Thus, on 27 October, going north toward Tambo de Mora, a station was taken where the temperature at the time was not extraordinarily high (20·5°C at the surface, 16°C at 5 metres and 14·7°C at 43 metres). The zooplankton nets came up loaded with a yellow-brown slime from decaying phytoplankton. We have no information as to the organisms concerned, but it is possible that they may have been the naked flagellate (VOGT, 1942, Photo A, opposite p. 111) observed at Pisco in considerable numbers at about this time. Two days later (29 October), there were dead sea slugs on the beach at Chincha Norte and on 30 October, dead " lissas " were reported at La Puntilla. Meanwhile a visitor from Lima (1 November) reported a putrefactive stench, characteristic of an " aguaje " all the way down the coast from Callao (cf., BRONGERSMA-SANDERS, 1948; RAHM, 1927; WOODCOCK, 1948). Yet that same day the birds had fed in the Bay and over the weekend (3-4 November), Pisco Bay was teeming with life, the whales mentioned above, anchovies, Munida, gray gulls, etc., in addition to the usual guano birds.

In most cases, " red water " is chiefly due to a very dense concentration of dinoflagellates (BRONGERSMA-SANDERS, 1948), with the individuals in any one swarm usually belonging to but one species. From one half to one million cells per litre merely give the appearance of a dingy chocolate colour to the water, a colour often seen on the Peruvian coast. If the number doubles the water becomes distinctly red (ALLEN, 1942). Apparently, dinoflagellates bloom most frequently at times when the water temperature is relatively high. They occur in boreal waters after the flowering of diatoms (BIGELOW, 1927), when the water there is warmest. Just as is

[16]BHIMACHAR and GEORGE, 1950; BRONGERSMA-SANDERS, 1948; CHEW, 1953; CONNELL and CROSS, 1950; COPENHAGEN, 1953; DAVIS, 1948; GUNTER, *et al.*, 1948; HAYES and AUSTIN, 1951; SOMMER and CLARKE, 1948.

the case for diatoms (BIGELOW, LILLICK and SEARS, 1940, p. 169), no one factor appears to stimulate their increase. Recently, it has been suggested that small water masses of low salinity appear to be favourable for the growth of a " red tide " (SLOBODKIN, 1953). Certain species of dinoflagellates do actually show a maximal reproductive rate when salinities are low (BRAARUD, 1951; NORDLI, 1953). In view of the extremely slight runoff from streams entering Pisco Bay, it seems unlikely that similar conditions favour the development of an " aguaje " on the Peruvian coast. Earlier, KETCHUM and KEEN (1948) found 2½ to 10 times the maximal total of phosphorus to be expected in the sea during a " red tide " off the west coast of Florida. Thus, they seem to exclude the possibility that the blooms necesarily depend on upwelled, nutrient rich water. In some cases, it is believed that dinoflagellates become concentrated by convection cells (BARY, 1953). In short, it is unlikely that optimal conditions are the same for all species which may cause " red water."

An intrusion of a foreign water mass such as " El Niño " or offshore water is not a prerequisite for either type of biological disaster. It is now established that the upwelled water of the Peruvian Current may also produce such a bloom when it has warmed in the surface layers to a temperature of 20°C as described earlier. It seems likely that little further headway can be made in determining limiting factors other than heat, until some record of the species concerned together with the environmental conditions is made.

DISCUSSION

The problem presented above is obviously not a simple one and is far from solved. Much headway could be made with more quantitative information of the upwelling process similar to that obtained recently along the Californian coast (California, Marine Research Committee, 1953). There, not only have many more centres of upwelling been discovered in the last five years than had been previously known, but also a method is in course of development for measuring the intensity of upwelling in different localities. These studies show that the intensity of upwelling fluctuates from year to year, just as appears to be true on the Peruvian coast. An attempt was made in the work along the California coast to correlate the intensity of upwelling with an increasing wind stress. Although weather cycles are recognized on the Peruvian coast (RUDOLPH, 1953; WILLETT and RUBIN, 1953) sufficient data have not accumulated there to determine any relationship between upwelling and meteorological phenomena. Such data, together with model studies in the laboratory (VON ARX, 1952) should provide significant clues for an understanding of the ecology of the Peruvian Coastal Current.

Consideration must also be given in future to the cycle of nutrient salts. Throughout the present paper, it has been assumed that they are usually in excess and that their disappearance when upwelling ceases may indirectly account for the disappearance of the anchovies. The question is complicated by the fact that it is not known whether the excreta of the birds make any significant contribution to the abundance of nutrients in the water. In a very limited area within a bay on Long Island, New York, it is estimated that four million ducks produce 2·7 million pounds of nitrogen and 0·82 million pounds of phosphorus per year (Woods Hole Oceanographic Institution, 1952). The uric acid deposited in the water is quickly changed into soluble nitrogenous compounds by bacteria. At the height of the season, small

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green algae are extremely numerous rather than more characteristic diatoms and dinoflagellates, possibly due to the abnormal nitrogen-phosphorus ratio. This suggests that in the vicinity of a guano island, despite a substantial deposit of guano on the island itself, there may also be a significant contribution to the surface waters. This might account for the dense population of a large naked flagellate in the latter part of October, when several million cormorants were nesting in the Ballestas.

Clarification of these two questions together with work presently in progress on the life history of the anchovy will go a long way toward accounting for the fluctuations in the amount of guano deposited on the islands from year to year and to an understanding of the high productivity of an area of active upwelling.

SUMMARY

1. The ecological situation in the Peruvian Coastal Current is reviewed.

2. It is suggested that during catastrophic periods, warming *in situ* in the absence of active upwellings is perhaps more frequent than a phenomenal incursion of " El Niño " like that of 1925 or of warm offshore water. Contributions from rivers appear negligible for the area as a whole.

3. Some consideration is given to the cooling process and its possible effect on the annual temperature cycle.

4. The annual temperature range appears to be about 7°C. and the salinity range less than 2‰, compared with a temperature range of 20°C or more and a salinity range of perhaps 6‰ in temperate coastal waters.

5. There are two types of biological disasters, both usually associated with warm water and formerly attributed to " El Niño." One is the series of events initiated by disappearance of the anchovies, the other by the development of " red water." The latter has been found not only as a consequence of an incursion of " El Niño " and of warm offshore water, but also in upwelled water which has warmed in the surface layers.

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Woods Hole Oceanographic Institution, Woods Hole Mass., U.S.A.

Table 1. *Data for stations occupied in vicinity of Cabo Blanco and Lobitos from "El Lobito"*

Station	*CB* 1-2 *mi. W. Lobitos buoys*		*CB* 2-6 *mi. W. Lobitos buoys*		*CB* 3-14 *mi. W. Lobitos buoys*		*CB* 4-1 *mi. W. C. Blanco*	
Date	17 *Jan.* 1942		17 *Jan.* 1942		17 *Jan.* 1942		19 *Jan.* 1942	
Total depth (m)	40		*more than* 200		—		85	
Depth in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	21·4	34·80	21·4	34·65	21·8	34·78	20.6	34·76
5	21·2	broken	21·3	34·65	21·6	34·78	20·5	34·78
10	21·1	34·81	21·2	34·70	21·2	34·79	20·5	34·76
25	20·0	34·81	21·0	34·70	21·0	34·81	18·9	34·85
39	18·7	broken	–	–	–	–	–	–
50	–	–	18·6	34·94	18·4	34·97	17·6	34·99
75	–	–	–	–	–	–	17·0	–
100	–	–	16·5	35·03	16·3	35·07	–	–
200	–	–	14·5	34·99	14·6	broken	–	–

Station	*CB* 5-9 *mi. W. C. Blanco*		*CB* 6-20 *mi. W. C. Blanco*		*CB* 7-32-35 *mi. W. C. Blanco*		*CB* 8-1·5 *mi. W. C. Blanco*		*CB* 9-9 *mi. NW. C. Blanco*	
Date	19 *Jan.* 1942		19 *Jan.* 1942		20 *Jan.* 1942		21 *Jan.* 1942		21 *Jan.* 1942	
Total depth (m)	—		—		—		100		—	
Depth in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	21·6	34·72	22·0	34·70	22·6	34·74	21·1	34·74	21·6	34·70
5	21·5	34·70	21·9	34·70	22·5	34·72	21·0	34·74	21·6	34·72
10	21·1	34·76	21·8	34·69	22·2	34·72	19·6	34·82	20·5	34·83
25	20·1	34·85	20·0	34·85	22·1	34·74	18·6	34·87	19·6	34·87
50	18·6	34·90	18·8	34·97	18·4	35·01	16·1	35·01	18·6	34·94
95	–	–	–	–	–	–	15·9	35·01	–	–
100	16·8	35·01	16·8	35·03	16·5	35·07	–	–	16·5	35·02
200	14·3	34·97	14·7	34·99	15·0	35·03	–	–	13·8	34·97

Table 2. *Data for stations occupied in the vicinity of Pisco Bay in* 1941.

A. Regular series of stations

Sta. P 1. Roughly 5 miles east of Chincha Norte.

Date	5 *Sept.*		16 *Sept.*	22 *Sept.*	3 *Oct.*	23 *Oct.*	6 *Nov.*	24 *Nov.*	8 *Dec.*
Total depth (m)	67		69	57	57	58	58	59	47
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·8	17·0	16·1	16·8	16·9	19·0	16·0
5	16·7	35·06	17·3	17·0	16·0	16·8	16·9	15·8	15·6
10	–	–	16·1	17·0	15·6	16·7	16·4	15·5	15·5
25	14·8	–	15·1	15·1	14·8	15·0	15·3	15·0	14·8
50	14·3	–	14·4	14·7	14·4	14·7	15·0	15·0	14·6
60	–	–	14·4	–	–	–	–	–	–

Table 2 (continued)

Sta. P 2. Roughly 5 miles toward Pisco from Station P 1.

Date	*5 Sept.*		*22 Sept.*	*3 Oct.*	*23 Oct.*	*6 Nov.*	*24 Nov.*	*8 Dec.*
Total depth (m)	13		10	9	8	7	9	9
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	18·3	15·6	16·5	18·0	16·6	16·0
4	19·4	–	–	–	–	–	–	–
5	–	35·06	18·1	15·6	16·1	16·5	16·2	15·6
8	18·0	–	17·8	–	–	–	–	–

Sta. P 3. Roughly 5 miles toward Ballestas from Station P 2.

Date	*5 Sept.*		*16 Sept.*	*22 Sept.*	*3 Oct.*	*23 Oct.*	*6 Nov.*	*24 Nov.*	*8 Dec.*
Total depth (m)	55		68	59	56	54	59	63	61
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	18·3	18·3	16·5	16·7	17·5	17·1	16·6
5	18·6	35·11	17·9	17·2	15·6	16·4	16·8	16·3	15·4
10	–	–	16·6	16·3	15·4	15·8	16·4	15·1	15·1
20	15·2	–	–	–	–	–	–	–	–
25	–	–	15·2	15·0	14·7	14·8	15·8	14·9	14·7
40	14·5	35·00	–	–	–	–	–	–	–
50	–	–	14·5	14·6	14·4	14·6	15·0	14·6	14·6

Sta. P 4. Roughly 5 miles west of Ballestas.

Date	*9 Sept.*		*22 Sept.*	*3 Oct.*	*23 Oct.*	*6 Nov.*	*24 Nov.*
Total depth (m)	122		119	110	121	120	118
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·5	17·1	17·4	19·2	18·0
5	16·8	35·01	17·1	16·0	16·2	16·9	17·2
10	–	–	16·6	15·5	16·0	16·4	15·0
25	14·4	35·00	14·8	14·9	15·9	15·7	14·6
50	14·8	35·04	14·2	14·2	14·9	14·8	14·5
75	14·6	34·96	14·1	–	–	–	–
100	–	–	14·0	14·0	13·9	14·2	14·2

Table 2 (continued)

Sta. P 5. Roughly 5 miles west of Chincha Norte.

Date	9 *Sept.*		24 *Sept.*	7 *Oct.*	25 *Oct.*	8 *Nov.*	28 *Nov.*	10 *Dec.*
Total depth (m)	122		124	134	117	120	127	121
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·1	16·3	17·0	18·0	18·0	16·2
5	16·2	35·00	17·0	15·6	17·0	18·0	17·0	16·0
10	–	–	15·5	15·6	17·0	17·8	16·2	15·9
25	14·5	34·99	14·6	14·7	16·1	16·9	15·3	15·0
50	14·0	–	14·2	14·4	14·7	14·6	14·6	14·8
75	13·8	–	–	–	–	–	–	–
100	–	–	14·0	14·2	13·7	13·9	14·5	13·6
115	–	–	13·9	–	13·6	–	–	–
125	–	–	–	14·2	–	–	–	–

Sta. P 6. Roughly 3 miles north of Chincha Norte through 7 October, thereafter 5 miles north of Chincha Norte.

Date	9 *Sept.*		16 *Sept.*	24 *Sept.*	1 *Oct.*	7 *Oct.*	13 *Oct.*	25 *Oct.*	29 *Oct.*	8 *Nov.*	28 *Nov.*	10 *Dec.*
Total depth (m)	87		92	95	91	97	88	95	86	101	97	91
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·1	17·7	16·9	17·2	15·8	17·7	20·1	19·8	21·6	17·6
5	19·5	35·02	16·6	17·4	16·0	16·2	15·3	16·0	18·6	18·5	19·4	15·6
10	–	–	16·1	16·5	15·8	16·6	15·1	16·0	15·6	17·2	15·4	15·5
25	15·4	35·01	15·0	15·1	14·7	14·9	14·7	15·1	15·0	15·9	15·1	15·0
50	14·2	–	14·3	14·3	14·3	14·5	14·4	14·5	14·5	14·4	14·7	14·5
70	14·0	34·98	14·1	14·0	14·2	14·2	13·6	14·2	14·5	14·0	–	–
80	–	–	–	–	–	–	–	–	–	–	–	14·0
97	–	–	–	–	–	–	–	–	–	–	14·5	–

Sta. P 7. Roughly 3 miles south of San Gallán and about 3 miles west of Point Huacas.						Sta. P 8. Roughly 5 miles west of P 7.				
Date	11 *Sept.*		9 *Oct.*	14 *Nov.*	2 *Dec.*	11 *Sept.*		9 *Oct.*	14 *Nov.*	30 *Nov.*
Total depth (m)	92		93	90	86	174		193	190	188
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	16·7	15·8	17·6	–	–	17·9	16·6	17·9
5	15·0	35·02	15·4	15·8	16·6	16·3	34·99	15·9	16·4	17·7
10	–	–	15·0	15·4	16·0	–	35·04	15·3	16·0	17·1
25	14·2	35·00	14·9	15·3	15·3	14·4	–	15·0	15·6	16·6
50	13·9	35·00	14·4	14·6	14·6	14·8	–	14·2	14·4	14·5
75	13·8	34·98	14·2	14·4	–	–	–	13·9	14·0	–
80	–	–	–	–	14·1	–	–	–	–	–
100	–	–	–	–	–	14·4	–	–	–	14·0
150	–	–	–	–	–	14·2	–	–	–	–
180	–	–	–	–	–	–	–	–	–	13·0
185	–	–	–	–	–	–	–	–	13·6	–

Table 2 (continued)

	Sta. P 9. Roughly 10 mi. W. of Chincha Norte.	Sta. P 10. Roughly 10-12 mi. N. of P 5.			Sta. PA. Roughly 3 mi. from P 6 toward Pisco.	Sta. PB. Roughly 9 mi. toward Pisco from P 6.
Date	7 *Oct.*	25 *Oct.*	8 *Nov.*	28 *Nov.*	16 *Sept.*	16 *Sept.*
Total depth (m)	148	94	114	99	72	25
Depths in (m)	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	16·1	17·1	19·3	19·9	17·6	17·6
5	16·2	16·8	17·7	18·4	17·0	17·2
10	15·7	16·4	17·4	15·5	16·5	17·2
20	–	–	–	–	–	16·0
25	15·0	15·7	16·0	14·9	15·1	–
50	14·7	14·5	14·5	14·7	14·4	–
65	–	–	–	–	14·2	–
75	–	–	–	–	–	–
90	–	14·3	–	14·5	–	–
100	14·2	–	14·0	–	–	–
140	14·0	–	–	–	–	–

B. Miscellaneous stations.

Locality	1 mi. W. Pt. Huacas	About 4 mi. E. of Sta. P6	About 3 mi. toward Chincha Norte from previous column	Chincha Norte Station	Line of stations La Puntilla-Chincha Norte	
					About 4 mi. from La Puntilla	About 8 mi. from La Puntilla
Date	9 *Oct.*	29 *Oct.*	29 *Oct.*	29 *Oct.*	30 *Oct.*	30 *Oct.*
Total depth (m)	49	57	79	—	20	39
Depths in (m)	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	16·2	20·6	20·0	21·1	20·3	19·7
5	16·1	18·5	19·3	18·4	18·0	16·7
10	14·6	15·9	16·9	16·9	16·1	15·3
15	–	–	–	–	15·2	–
25	–	15·0	15·1	15·2	–	15·0
35	–	–	–	–	–	14·9
40	14·8	–	–	–	–	–
50	–	14·6	14·6	14·5	–	–
75	–	–	14·6	–	–	–

Table 2 (continued)

Locality	Line of stations La Puntilla-Chincha Norte		About 1 mi. W. Ballesta Is.	About 2 mi. W. Pt. Huacas	About 7 mi. W. Pt. Huacas	Chincha Norte Station	
	12 mi. from La Puntilla	16 mi. from La Puntilla					
Date	30 *Oct.*	30 *Oct.*	31 *Oct.*	31 *Oct.*	31 *Oct.*	6 *Nov.*	28 *Nov.*
Total depth (m)	68	65	75	83	202		
Depths in (m)	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	19·6	21·3	16·9	16·9	16·9	20·2	19·9
5	18·4	18·9	16·9	16·7	16·7	19·8	18·5
10	15·6	17·0	15·9	15·9	16·4	17·7	15·8
25	14·7	15·2	14·9	14·8	16·0	15·5	15·1
50	14·4	14·4	14·5	14·6	14·8	14·6	14·6
70	–	–	14·4	–	–	–	–
75	–	–	–	14·4	–	–	–
100	–	–	–	–	14·0	–	–
195	–	–	–	–	13·0	–	–

C. Stations taken from the "Pacific Queen"

Locality	P 11 about 9 mi. toward Tambo de Mora from Chincha Norte		P 12. About 13·5 mi. toward Tambo de Mora from Chincha Norte		P 13. About 4·5 mi. W. P 12	P 14. About 9 mi. W. P 12		P15. 13·5 mi. W. P 12
Date	27 *Oct.*		27 *Oct.*		27 *Oct.*	27 *Oct.*		27 *Oct.*
Total depth (m)	38		11		52	91		110
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*
0	17·6	35·07	20·0	35·07	20·6	18·3	35·03	19·6
5	15·9	35·03	17·3	35·05	16·0	16·3	35·01	19·4
6	–	–	–	–	15·4	–	–	–
7	–	–	–	–	15·2	–	–	–
8	–	–	16·2	35·02	–	–	–	–
10	15·4	35·03	–	–	15·2	16·0	35·01	17·3
25	15·2	35·03	–	–	14·9	15·1	35·01	16·0
43	–	–	–	–	14·7	–	–	–
50	–	–	–	–	–	14·4	35·01	14·5
75	–	–	–	–	–	14·2	35·01	–
100	–	–	–	–	–	–	–	14·2

Table 2 (continued)

Locality	P 16. 18 mi. W. P 12		P 17. About 9 mi. W. of Chincha Norte		P 18. About 22·5 mi. W. Chincha Norte		P 19. About 36 mi. W. Chincha Norte	
Date	27 *Oct.*		28 *Oct.*		28 *Oct.*		28 *Oct.*	
Total depth (m)	120		129		255		over 200	
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	18·8	35·03	17·7	35·07	18·0	35·17	18·6	35·17
5	18·3	35·03	17·3	35·10	17·9	35·30	17·9	35·14
10	17·6	35·03	17·2	35·07	17·9	35·17	17·9	35·14
25	16·4	35·10	16·2	35·07	17·9	35·28	17·8	35·14
50	15·1	34·96	14·5	34·96	16·3	35·12	16·1	35·14
100	14·2	35·01	14·0	34·96	14·0	34·97	–	35·16
200	–	–	–	–	12·7	34·88	12·5	34·88

Locality	P 20. About 13·5 mi. W. Chincha Norte		P 21. About 27 mi. W. Chincha Norte		P 22. About 40·5 mi. W. Chincha Norte		P 23. About 112·5 mi. W. Chincha Norte	
Date	15 *Dec.*		15 *Dec.*		15 *Dec.*		16 *Dec.*	
Total depth (m)	157		over 200		over 200		over 200	
Depths in (m)	*Temp. in °C.*		*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	17·8		18·6	35·08	21·8	35·19	22·0	35·49
5	17·3		17·6	35·09	21·5	35·20	21·9	35·49
10	16·4		17·2	35·08	21·2	35·19	21·9	35·49
25	16·0		16·6	35·15	18·8	35·22	21·0	35·40
50	15·0		15·6	35·07	17·0	34·96	18·0	35·40
100	15·0		14·0	34·96	14·3	34·87	15·3	34·96
150	13·5		–	–	–	–	–	–
200	–		12·8	34·93	13·0	–	14·3	34·79

Locality	P 24. About 31 mi. E. P 23.		P 25. About 27 mi. E. P 24*	
Date	16 *Dec.*		16 *Dec.*	
Total dep.h (m)	over 200		over 200	
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	21·3	35·24	21·0	35·18
5	21·1	35·24	20·5	35·17
10	21·1	35·24	20·3	35·20
25	20·9	35·29	20·3	35·36
50	20·3	35·44	19·6	35·31
100	18·2	35·22	17·0	34·97
200	13·5	34·87	16·6	34·96

* The positions of the stations for 15 and 16 December are inaccurate. A course was set due West until reaching Sta. P 23 and then due East. At about midnight of 16 December, the " Pacific Queen " reached the light at Los Infiernillos about 1° of latitude south of Chincha Norte. This should not be interpreted as necessarily due to a current, since the ship's compass had not been adjusted recently.

Table 3. Weekly temperature observations down to 50 m. in offing of Chincha Norte taken by Mr. William Vogt and Señor Enrique Avila

Metres	1940 13 Oct.	20 Oct.	27 Oct.	10 Nov.	17 Nov.	1 Dec.	8 Dec.	15 Dec.	29 Dec.	1941 5 Jan.	12 Jan.	19 Jan.	16 Feb.
0	17·0	17·6	17·9	17·6	17·1	19·0	20·9	19·3	20·6	21·0	21·8	21·7	21·0
10	17·0	17·3	17·3	17·5	16·8	15·0	17·2	17·0	19·1	18·2	19·0	19·2	20·5
20	15·6	15·0	15·2	14·6	16·7	15·0	14·6	15·5	16·2	17·0	17·2	18·3	20·0
30	14·5	14·5	14·5	14·1	16·5	15·0	14·5	15·1	15·9	16·0	16·3	16·0	19·0
40	14·5	14·5	14·5	14·0	15·0	–	14·5	15·0	15·5	15·6	15·5	15·4	18·5
50	14·0	14·0	14·4	14·0	14·5	–	14·0	14·9	15·1	15·2	15·4	15·2	18·2
Average*	15·4	15·0	15·1	15·2	16·1	–	15·6	15·9	16·9	16·9	17·3	17·4	19 5

Metres	1941 23 Feb.	2 Mar.	9 Mar.	16 Mar.	30 Mar.	13 Apr.	20 Apr.	27 Apr.	4 May	11 May	18 May	8 June	16 June
0	22·0	24·0	24·0	23·3	22·0	19·5	18·7	18·6	19·6	19·9	20·0	19·0	18·4
10	21·0	23·2	23·0	22·2	21·3	19·4	18·6	18·4	19·4	19·2	19·0	18·9	17·0
20	19·6	20·1	20·6	21·8	21·2	19·0	18·0	18·0	18·9	18·3	18·0	18·8	16·2
30	19·5	19·9	19·9	21·2	20·9	18·8	17·4	17·8	18·2	17·8	17·2	18·6	15·7
40	19·2	19·1	19·7	20·9	20·3	18·2	17·2	17·6	17·5	17·2	17·0	18·0	15·0
50	19·0	18·9	19·5	20·3	20·2	18·0	17·0	17·0	17·0	17·0	16·1	17·0	14·9
Average	19·9	20·7	20·9	21·5	20·9	18·8	17·8	17·9	18·4	18·2	17·8	17·4	18·1

Metres	1941 7 Sept.	14 Sept.	21 Sept.	28 Sept.	12 Oct.	26 Oct.	2 Nov.	9 Nov.	23 Nov.	30 Nov.	7 Dec.	14 Dec.
0	16·0	17·4	17·4	16·8	15·5	18·5	19·0	17·7	19·6	18·5	16·5	19·0
10	14·5	17·1	17·2	15·9	15·4	18·3	18·0	17·6	16·4	15·6	16·3	17·5
20	14·0	15·0	16·7	14·9	15·2	15·2	16·0	15·8	15·0	15·3	15·7	15·7
30	14·0	14·6	15·3	14·5	15·0	15·1	15·6	15·4	14·7	15·0	15·0	14·7
40	13·9	14·0	14·8	14·4	15·0	14·7	14·8	15·0	14·5	14·7	14·9	14·6
50	13·9	13·9	14·6	14·4	15·0	14·4	14·7	14·7	14·4	14·6	14·8	14·6
Average	14·2	15·6	16·0	15·0	15·2	15·9	16·2	15·9	15·5	15·4	15·5	15·8

* The average for the column 50 metres deep was obtained by adding one-half the surface temperature, one-half the temperature at 50 metres and the temperatures at 10 m, 20 m, 30 m, and 40 m and dividing by 5.

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The age of the sediment collected at *Challenger* (1875) Station 225 and the distribution of *Ethmodiscus rex* (Rattray)

WILLIAM R. RIEDEL*

Summary—The sediment sample collected by H.M.S. *Challenger* in 1875 at her Station 225 is shown to be from an outcrop of Middle Tertiary age. Therefore the presence of the diatom *Ethmodiscus rex* (Rattray) in this sediment sample is not the result of its having lived in the overlying waters in Recent geological time. In two other recorded occurrences, this diatom is believed to be associated with other sedimentary constituents which are, at least in part, of Tertiary age. Five of the Radiolaria occurring at *Challenger* Station 225 are discussed briefly.

THE SEDIMENT SAMPLE FROM *CHALLENGER* (1875) STATION 225

IN a discussion of the distribution of the large diatom *Ethmodiscus rex* (Rattray), WISEMAN & HENDEY (1953) record its occurrence in the sediment collected at Station 225 of the original *Challenger* expedition (at 11°24·0′N 143°16·0′E; depth 4475 fm). This has brought into added prominence a question which has interested the author for some time – namely, what is the age of this sample of radiolarian ooze? Many of the 140 species of Radiolaria which HAECKEL (1887) mentions as occurring at this station are strikingly different from those found in most other Pacific sediments. Recent examination of deep-sea sediments collected in the Pacific by the Swedish Deep-Sea Expedition and by various American expeditions has indicated that outcrops of Tertiary sediment occur not infrequently on the floor of the deep ocean, and that, in many other localities, reworked Tertiary microfossils are mixed with the Recent sediment at the surface of the sea floor. If the sediment at *Challenger* Station 225 is Tertiary in age, the occurrence of *Ethmodiscus rex* at that locality has little bearing on the present-day distribution of that diatom.

Dr. J. D. H. WISEMAN, of the British Museum (Natural History), has kindly sent the author small portions from three different places in the short core obtained at Station 225, and examination of the Radiolaria in these samples (Brit. Mus. (Nat. Hist.), Reg. No. M289) shows that none of the forms which are abundant in purely Recent Pacific sediments are present. Thus it is probable that the sediment is purely Tertiary in age, and comparison of the contained Radiolaria with assemblages of known Tertiary ages should enable us to date the fauna approximately. The dating of Tertiary sediments on the basis of the Radiolaria which they contain is one of the least-developed facets of micropalaeontology, but the following comments on the distribution of a few of the more abundant and characteristic species occurring at Station 225 indicate that an approximate age can be assigned to the sediment. Although the five species discussed below represent only a small fraction of the total number present, they are considered to be sufficient for an approximate age assignment – a more complete discussion of the species in this sample must await a thorough reconsideration of all the *Challenger* Radiolaria from a descriptive and taxonomic point of view. The radiolarian assemblage shows practically no variation in the three

* Contribution from the Scripps Institution of Oceanography, new series, no. 696.

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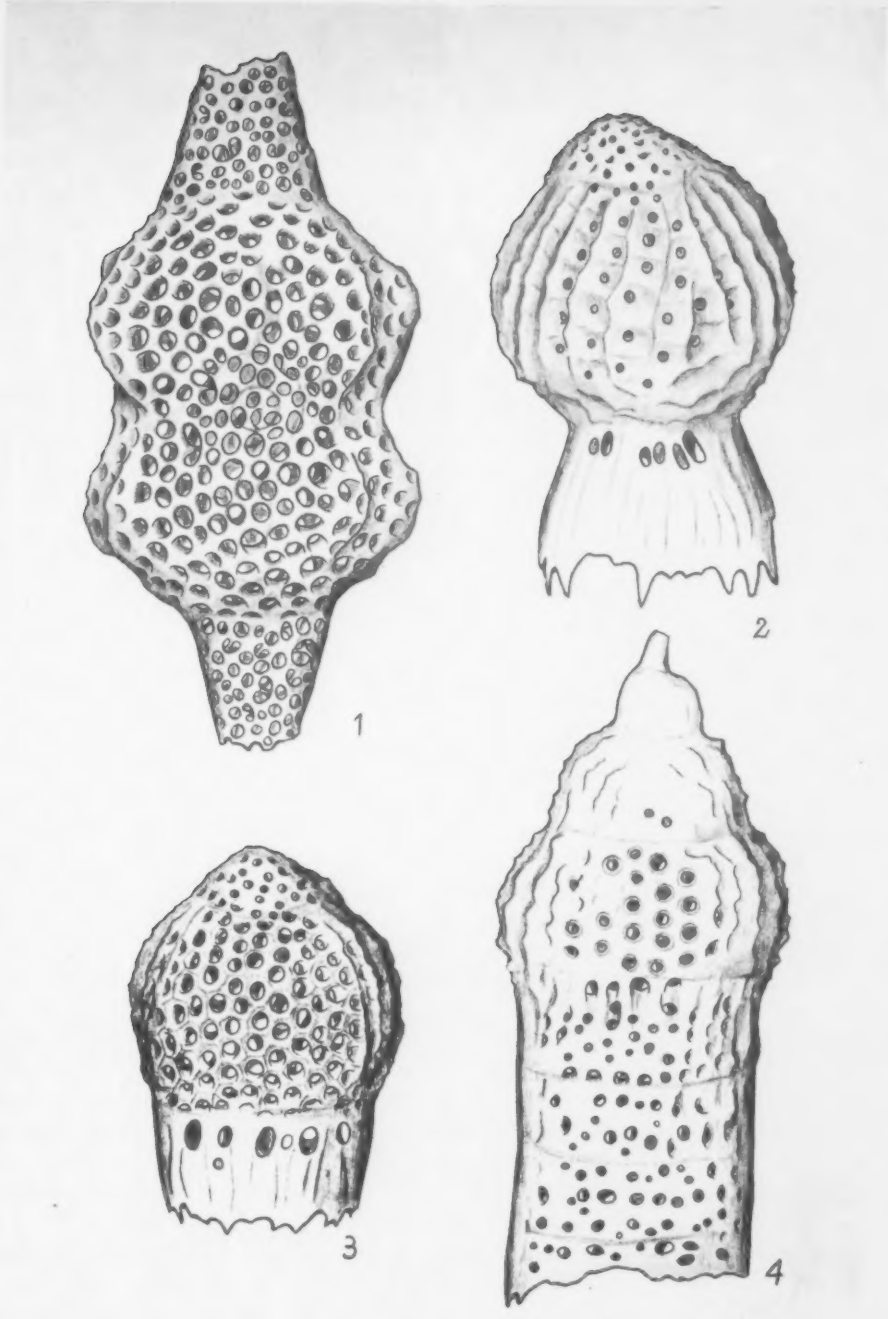

PLATE I. Radiolaria from *Challenger* (1875) Station 225, all x 475.
Fig. 1. *Cannartidium ? mammiferum* Haeckel. Figs. 2, 3. *Cycladophora favosa* Haeckel.
Fig. 4. *Stichocorys ? wolffii* Haeckel.

samples examined; each of the Radiolaria listed below was found in all three samples.

Cannartidium ? mammiferum Haeckel.—The systematic classification of the members of HAECKEL's families Artiscida, Cyphinida, Panartida and Zygartida (which together comprise the " family Artiscidae Haeckel emend." of DEFLANDRE, 1953, pp. 416 and 418) is at present very unsatisfactory. Before the taxonomy can be revised, it will be necessary to re-examine all of the species concerned from their type localities. Preliminary investigations indicate, however, that some members of these families underwent rapid evolution during the Tertiary, and that they may therefore prove especially useful for age determinations. The form (Pl. 1, fig. 1) which is here tentatively identified as *Cannartidium mammiferum* Haeckel has less regular fenestrated protuberances on the cortical shell than shown in HAECKEL's figure, and the polar projections are often spongy rather than tubular; these differences are probably not of great taxonomic significance, and the form which occurs at *Challenger* Station 225 appears to be identical with, or very closely related to, the form which HAECKEL described under this name from *Challenger* Station 268. Specimens similar to those occurring at *Challenger* Station 225 have been found in many sediments of Middle Tertiary age, including the " Moronitas " (Burdigalian) of Muro, Mallorca (see COLOM & GAMUNDI, 1951); the Cipero formation (Upper Oligocene of CUSHMAN & STAINFORTH, 1945) at Retrench Quarry and Golconda Estate, Trinidad;* and in the Upper Oligocene or Lower Miocene siliceous clay of the islet off the NE corner of Colebrooke Island, Andaman Islands* (see JACOB & SHRIVASTAVA, 1952).

Tympanidium binoctonum Haeckel.—This species, of which *Challenger* Station 225 is the type locality, has been found in many Middle Tertiary sediments, in both subaerial and submarine localities. It occurs, for example, in the Oligocene chalky marl of the sea cliff along the highway, ½ mile SE of the plaza in Jeremie, Haiti; in the Cipero formation (Upper Oligocene) at Golconda Estate, Trinidad; in the Upper Oligocene or Lower Miocene siliceous clay of the islet off the NE corner of Colebrooke Island, Andaman Islands; and in the sediment at *Challenger* (1875) Station 268, which is suspected to be Upper Oligocene in age.

Cycladophora favosa Haeckel.—This species, of which *Challenger* Station 225 is the type locality, is rather difficult to identify. Specimens found by the present author usually have less pores on the post-thoracic part of the shell (Pl. 1, figs. 2 and 3), and thus approach the description of *Carpocanium palmipes* Haeckel, which was also described from this Station. However, HAECKEL's two figures of *Cycladophora favosa* indicate that the structure of the post-thorax is variable, and that the range of variation is probably sufficient to include the examples figured in this paper. This species has been found in the Oligocene chalky marl of the sea cliff along the highway, ½ mile SE of the plaza in Jeremie, Haiti; in the Cipero formation (Upper Oligocene) at Retrench Quarry and Golconda Estate, Trinidad; in the Upper Oligocene or Lower Miocene siliceous clay of the islet off the NE corner of Colebrooke Island, Andaman Islands; and in the (probably Upper Oligocene) sediment at *Challenger* (1875) Station 268.

Calocyclas virginis Haeckel.—*Challenger* Station 225 is the type locality of this

* TEMPÈRE & PERAGALLO (1907, p. 459) report " *Coscinodiscus rex* Wall." as occurring fossil in unspecified marine sediments of Trinidad. Fragments of large diatoms which in many respects resembly *Ethmodiscus rex* (Rattray) occur in the Cipero Formation of Trinidad and in the Middle Tertiary of the Andaman Islands, but the present author has been unable to confirm their identity with that species.

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species. It occurs also in the Cipero formation (Upper Oligocene) at Retrench Quarry and Golconda Estate, Trinidad; in the Upper Oligocene or Lower Miocene siliceous clay of the islet off the NE corner of Colebrooke Island, Andaman Islands; and in the (probably Upper Oligocene) sediment at *Challenger* (1875) Station 268.

Stichocorys ? wolffii Haeckel.—The abundant species of *Stichocorys* in this sample, and the one to which the name *S. wolffii* probably belongs, does not agree very well with HAECKEL's description and figure of that species. The cephalis and thorax usually have less pores than shown in HAECKEL's figure, and the longitudinal ridges on the thorax are usually less pronounced. The difference in the widths of the third and fourth segments is generally less than indicated by HAECKEL, and the post-abdominal segments are often more similar to those of his figure of *S. baerii* than to those of his figure of *S. wolffii*. A typical specimen is figured on Pl. 1, fig. 4. A species of *Stichocorys* closely resembling the form figured occurs in the Cipero formation (Upper Oligocene) at Retrench Quarry, Trinidad. *S. wolffii* occurs in the sediment at *Challenger* (1875) Station 268 (probably Upper Oligocene).

It will be seen from the above comments that the Radiolaria in the sediment from *Challenger* Station 225 indicate that the sample was taken from an outcrop of Middle Tertiary age (probably Upper Oligocene or Lower Miocene). Apart from the absence of the Radiolaria comprising the present-day Pacific fauna, and the presence of Middle Tertiary species, there is a certain amount of other evidence which seems to support the conclusion that the sediment sample is from a Tertiary outcrop. MURRAY & RENARD (1891, p. 204) state, of this sounding:- " The tube had sunk fully three inches into the deposit; the upper layers were of a red colour, and contained much more peroxide of manganese than the lower ones, which were of a pale yellow or straw colour . . . " The relative abundance of manganese dioxide in the upper layers of the sediment probably indicates a long period of very slow deposition, or non-deposition, during at least part of the time since the lighter-coloured lower layers were deposited. Also, the fact that " the whole of the lower part of the deposit when it came up had a very compact and laminated appearance," and that " it was difficult to separate the various components of the deposit the one from the other by shaking the whole in a bottle with water," may be taken to indicate that diagenetic changes of a low order had resulted in the solution of some of the organic silica, which was then re-deposited to form a cement which loosely bound the other constituents of the sediment; such low-grade lithification might be expected more commonly in Tertiary than in Recent deep-sea sediments.

SAMPLES OF *ETHMODISCUS* OOZE COLLECTED BY H.I.J.M.S. *KOSYU* IN 1933

HANZAWA (1933) and WISEMAN & HENDEY (1953) list the localities 9°21·0′N 146°50·0′E and 8°04·0′N 142°15·0′E as being included within the area of distribution of *Ethmodiscus* ooze, because the *Kosyu* obtained samples of that sediment at those localities in 1933. Here again the age of the sediment samples is an interesting problem, and it is not impossible that the *Ethmodiscus* frustules were deposited during the Tertiary. Two figures of one of these samples (HANZAWA, 1933, pl. 1, fig. 2; pl. 2, fig. 2) show considerable numbers of discoasters, and discoasters are mentioned in the description of the other sample (9°21′N 146°50′E): these microfossils can perhaps be used to date the sediment. Dr. M. N. BRAMLETTE and the present author are preparing a paper on the stratigraphic value of the discoasters, and our

investigations have revealed two points which have a bearing on the sediment samples under consideration. Firstly, the organisms which produced discoasters apparently lived only during the Tertiary. Secondly, the types of discoasters shown in HANZAWA's figures are restricted to the Upper Tertiary. Thus the sediment sample from 9°21′N 146°50′E is at least partly composed of pre-Recent material, and the sample from 8°04′N 142°15′E is partly or completely Upper Tertiary in age. Whether either or both of these samples were obtained from Tertiary outcrops, and whether the *Ethmodiscus* frustules were deposited during Tertiary or Recent time, could perhaps be determined by a more complete micropalaeontological examination of the original samples.

CONCLUSIONS

There is little doubt that the sediment obtained at *Challenger* Station 225 is from an outcrop of Middle Tertiary radiolarian ooze. The occurrence of *Ethmodiscus rex* in this sediment has no connection with its existence in the overlying waters at the present day, but rather means that the diatom lived in that region during Middle Tertiary time. Tertiary sediment is apparently present at two of the localities at which HANZAWA reported *Ethmodiscus* ooze, but the data at present available are not sufficient to indicate whether these two sediment samples are purely Tertiary, or mixtures of material of different ages. Thus the occurrence of *Ethmodiscus* in these two samples obtained by the *Kosyu* may result either from the existence of the diatom in the area during the Tertiary, or from its living there during Recent time.

Neither HANZAWA nor WISEMAN & HENDEY state that they believe that the frustules of *Ethmodiscus* in these three sediment samples have been formed and deposited during Recent geological time. Until recently, it has generally been assumed that practically all of the constituents of the sediments at the surface of the sea floor are of Recent origin. Investigations carried out during the last few years have indicated that this assumption is often invalid, at least in the tropical Pacific Ocean, and that a sediment which does not contain reworked, heterochthonous elements may be the exception rather than the rule. It has therefore become very important to consider the factor of time in all studies relating to deep-sea sediments. Our present knowledge of the palaeontology of many types of planktonic organisms is insufficient for their effective use in dating sediments, but their usefulness will doubtless increase rapidly with the expansion of deep-sea research. The planktonic Foraminifera can already be used for this purpose, and recent advances in our knowledge of the Tertiary Radiolaria, silicoflagellates, coccoliths and discoasters indicate that all of these groups of fossils may soon be employed in the determination of the ages of pelagic sediments.

Finally, it may be pointed out that many of the difficulties which attend research on Recent and Tertiary Radiolaria stem from fundamental faults in HAECKEL's classification of these organisms, and from the inadequacy of his species descriptions. Examples of these difficulties are to be found among even the small number of species mentioned earlier in this paper. A large proportion of all known Radiolaria were originally described by HAECKEL from the sediments collected by the *Challenger* expedition of 1873-76. In order to resolve these difficulties, therefore, it is necessary thoroughly to restudy the forms in the orginal samples. Because of the foresight of the authorities of the Challenger Office and of the British Museum (Natural

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History), portions of the *Challenger* samples have been preserved for almost a century, thus making possible the re-examination of this invaluable material.

The results included in this paper represent part of the author's research carried out during a visit to the U.S.A. which was made possible by the award of a John Murray Travelling Studentship in Oceanography and Limnology.

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A survey on deep-sea features taken during the Swedish deep-sea expedition

F. F. KOCZY

THE classification of submarine bottom features can be made in two different ways. One of them, followed by the International Committee on the Nomenclature of Ocean Bottom Features (WISEMAN and OVEY 1952), is descriptive in character. The features are classified by shape, extent and situation. The definitions have been chosen in such a way that they will not change, even if the theories about the origin of features changes with time, and developing knowledge. The other way would be to start from the forces which create the features. At the moment we are still at the beginning of our knowledge of these forces, hence the method can only be tentative. Since the progress of the science of the deep-sea has been great during recent years, there is sufficient information to make a start on the subject.

The essential point for such study seems to be the possibility of obtaining echograms of the microstructure of the sea floor. The circumnavigating Swedish Deep-Sea Expedition was the first to be equipped with an echosounder and recorder which could discriminate variations on the level of the sea-floor of only 1 m. The exaggeration was about 1 : 20 on the ship's mean speed. The horizontal distance could be read to about 20 m. This high precision was combined with great power, hence it was possible to receive echo from a depth of more than 9,000 m. The echosounder was supplied by Marine Instruments Ltd. (formerly Hughes & Son) London.

PRINCIPLE OF CLASSIFICATION

The morphological features are the result of the movement of masses. The task is to classify these masses in movement and the accelerations working on them, i.e. to look for the forces responsible for the morphological alterations. As the ocean bottom features, detected by echosounding, form the boundary between ocean water and ocean bottom, the forces belong partly to the water and partly to the sea-floor. The material moved by the forces originates also from the sea water and the earth's crust below the ocean bed. The time factor, too, will play a role; tremendous forces can in a short time move large masses, but on the other hand similar movements can be caused by continuously working, but weak forces.

The different forces work together in the ocean. On occasions one of them will be dominant, at times the other. The sequence of the dominant forces will be of importance for the actual morphology, but the last force in action will give the bottom its appearance.

The roughness of the sea bottom is taken as a guide to classification,, for with increased roughness the magnitude of the forces also grows. The classification follows the forces from the gravitation to the volcanic-tectonic forces.

THE FORCES IN ACTION

Supposing the primary ocean bed to be at rest and established, and if no weathering of the rocks occurs on the sea-floor, all particles in the ocean settle by gravitation. The

particles may be of terrigeneous origin or be formed in the sea water; in the latter case they are mainly of organic origin. The particles are transported by the ocean-currents and spread by the turbulence in the oceans. Bigger particles settle rapidly and come to rest geographically near their origin, but particles with a low settling rate can be transported in lateral direction over long distances. Through biological activity most of the finer particles are assembled into concentrations and the settling rate is thereby increased. It can also be supposed that with the skeletons clay particles are precipitated.

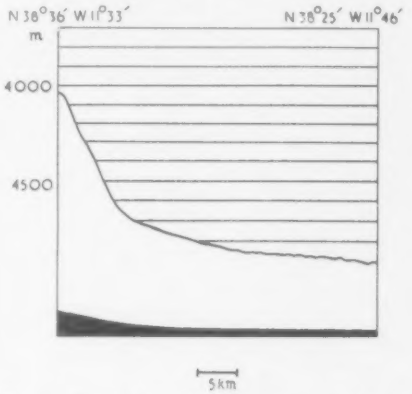

Fig. 2. Steep slope. The sediment surface in the flat bottom shows undulation presumably caused by sliding sediment downward the slope. In this and some of the following graphs the shaded part gives one tenth of the exaggeration of the profile drawn by a line.

The bottom topography seems to play an important role in the amount of sediment settled, because the dissolution of the skeletons is also influenced by the turbulence in the water-layer near the ocean-floor. Hence, not only does the sedimentation intensity change from place to place but also with time, dependent on the supply. On the tops of ridges and hills where the currents are stronger and the turbidity is increased, fine particles and the lighter organic material cannot be deposited, but coarse skeletons will settle there. Thus a separation of particles into coarse and fine material and into heavy and light particles is carried out by the currents. Material rich in organic matter will settle in depressions, and elsewhere where the currents are not strong (CORRENS 1935).

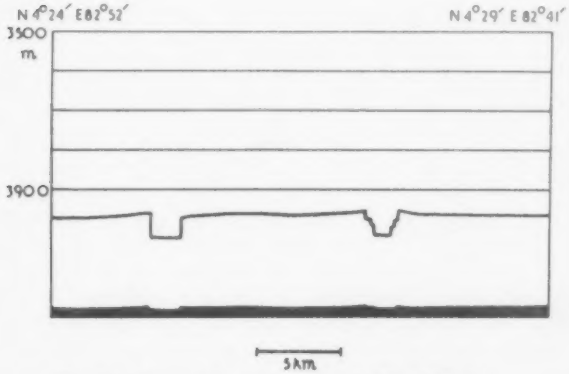

Fig. 3. Two of the fault-channels SE of Ceylon.

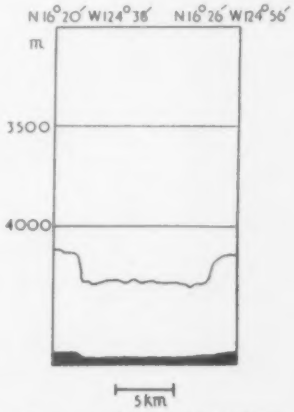

Fig. 4. A fault in the Eastern Pacific Ocean.

Once settled, the sediments undergo alterations. Chemical forces are now in action and continue at a low rate to change the composition and the lattice of the sediments. In the main it is the biological processes, such as bacteria-activity, which will furnish the necessary energy, but the exhalation of volcanoes will contribute to

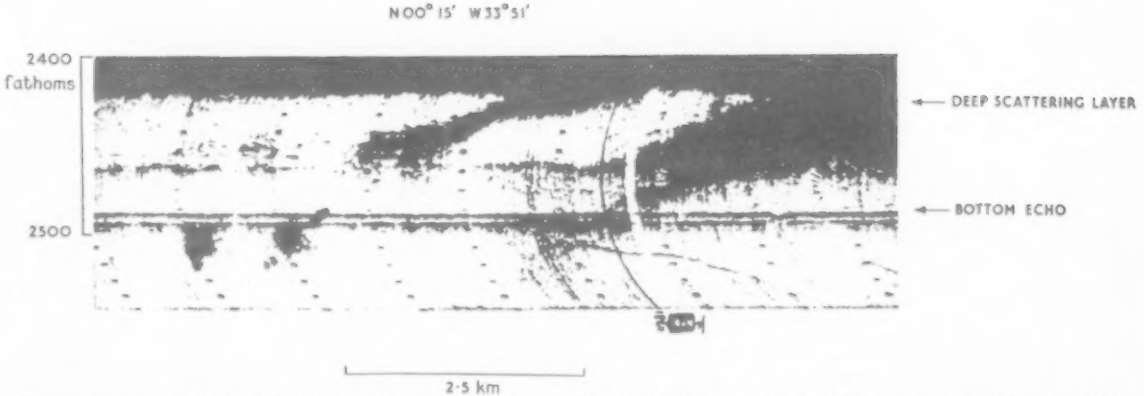

Fig. 1. The extremely flat bottom near the equator in the western basin of the Atlantic Ocean. The soundings have been taken between 1740 and 1840 local time and show three different deep scattering layers rising to the surface at sunset. The velocity of the vertical movements seems to be about 15 cm/sec.

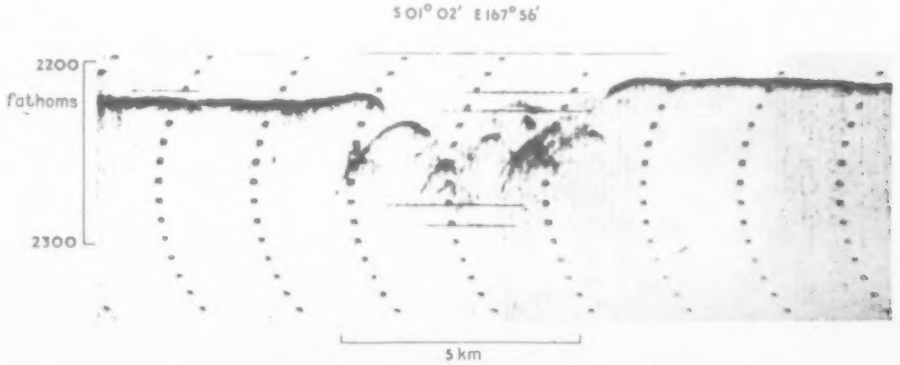

Fig. 5. Fault discovered on the flat bottom SE of Ceylon.

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this diagenesis. The alterations consist of dissolution of carbonates and silica, consolidation of the sediment by thixotropy and formation of gel, and the formation of new minerals and conglomerates.

It seems as if the sedimentation in combination with the deep-sea currents would work in the direction to smooth out all unevenness and to fill the deeper basins. But in reality a smooth sea-bottom is very seldom found. Other forces must be in action. We find them in the interior of the earth. This is not the place to discuss the different theories of endogenic forces but to point to the action of the horizontal and vertical forces within the earth's crust in the deeper layer under the ocean floor. All features known from the continents are found on the ocean-floor, and are not as easily altered as on the continents, because of the weakness of the destructive forces.

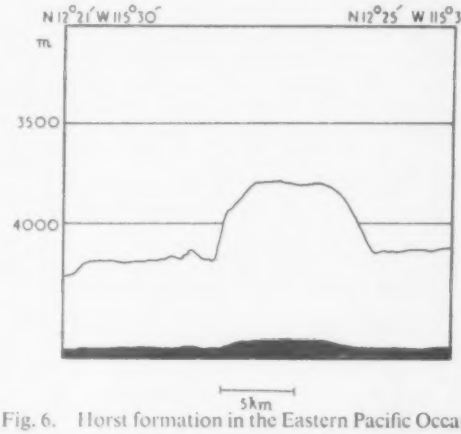

Fig. 6. Horst formation in the Eastern Pacific Ocean.

The equilibrium and the sequence of the tectonic and volcanic forces on one side, and the gravitation on the other, results in the relief of the ocean-floor. It is a very difficult task, by a study of the morphology alone, to detect which of the forces in every place was dominant. But, by studying the minor features, we get perhaps a hint of the forces involved. Starting from this point of view, the echosoundings with high dispersion, recording changes of 1 m by an exaggeration of 1 : 20, have made it possible to study closely the inter-relationship of these two main forces which give the deep-sea floor its appearance, and to reach a classification of the deep-sea features. But it will, of course, be only an attempt.

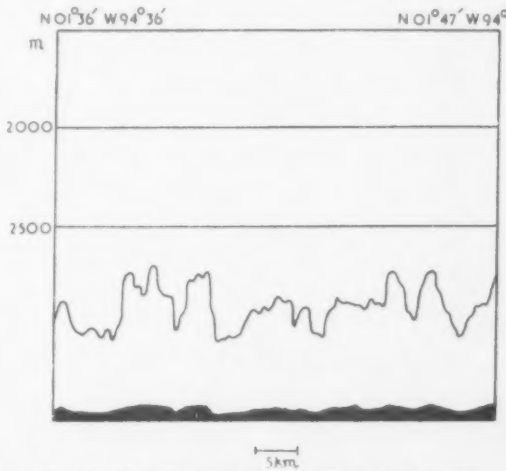

Fig. 7. Hill district in the Eastern Pacific Ocean.

THE PLAINS AND THEIR MINOR DISTURBANCES

The plains indicate that only the sedimentation process has been in action for a long geological period. The length of time during which no tectonic forces have disturbed the smoothing out process of sedimentation depends on the original roughness of the underlying profile and upon the rate of sedimentation. Plains have an extension of about 600 miles at

maximum. The Swedish Deep-Sea Expedition detected great plains situated south-west of Ceylon, in the western basin of the Atlantic from the equator to about 15°N, west of Madeir, west of Africa and north-west of New Guinea. The first two especially are real plains where no dip could be detected (Fig. 1), though here also we have found small disturbances. Near the shelf the surface is often undulating

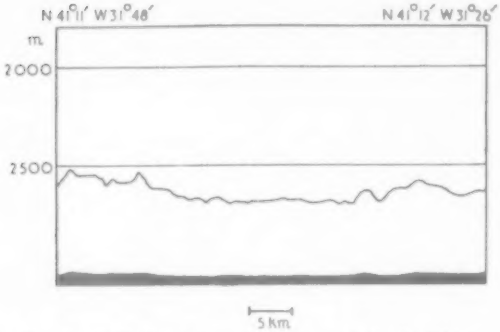

Fig. 8. Hill district on the Central Atlantic Ridge.

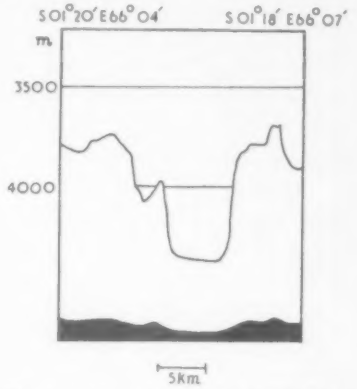

Fig. 9. A part of the Carlsberg Ridge in the Indian Ocean.

(Fig. 2) because of the pressure of the sediment sliding down the continental slope. This movement can be assumed to be very slow. Another disturbance of the plains was detected in the Central Indian Ocean plain (Fig. 3). DIETZ has proposed the explanation that turbidity currents are the cause of those valleys, but it seems very dubious since the sides are vertical and the deeper corners do not show a rounded

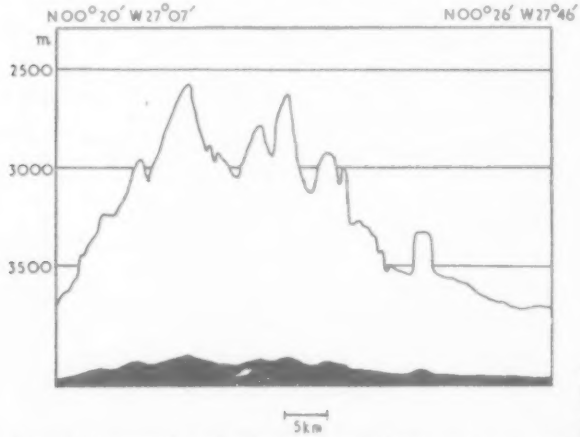

Fig. 10. A part of the Central Atlantic Ridge near the equator.

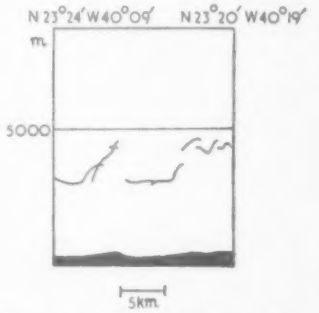

Fig. 11. The roughed surface (cross-overs) near the Central Atlantic Ridge. The profile is not corrected for the error caused by the wide beam angle.

profile, which should be the case if material has been transported into the valley. Similar features have been found in the Eastern Pacific, but on a bigger scale (Fig. 4). As we have also found features of about the same size but with a rough downdrawn side (Fig. 5), it can be supposed that all these are " Graben." Another indication that this explanation is right is the detection of horsts (Fig. 6).

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HILL DISTRICTS

The next step toward increased influence of the endogenic forces is shown by the hill districts. The features are of a similar nature and are explained as being disturbances of the plains, but they are bigger in size and more numerous. They are found on plateaus and on gently dipping slopes. One was crossed in the Pacific, north of the equator, at about 120° W. The hills are 50 to 300 m in altitude and a few hundred metres to about 10 km in diameter, more or less irregular in shape, but with the deepest parts level and the summits of about the same area (Fig. 7). That they are caused by strong endogenic forces seems to be established as they occur in the neighbourhood or in the centre of the environment where the action of endogenic forces is clearly demonstrated (near Clipperton Island and Gallapagos, and also near the Azores) (Fig. 8). They may be the result of a new arrangement of the sediment by earthquakes, but it seems very likely that they are produced by the stretching of the under-lying layers. Experiments with sediment on a rubber sheet give the same results. A shrinkage of the sediment cover as another possible explanation is very difficult to understand; but it may be possible if, by volcanic exhalation, the carbonates in deeper layers are dissolved.

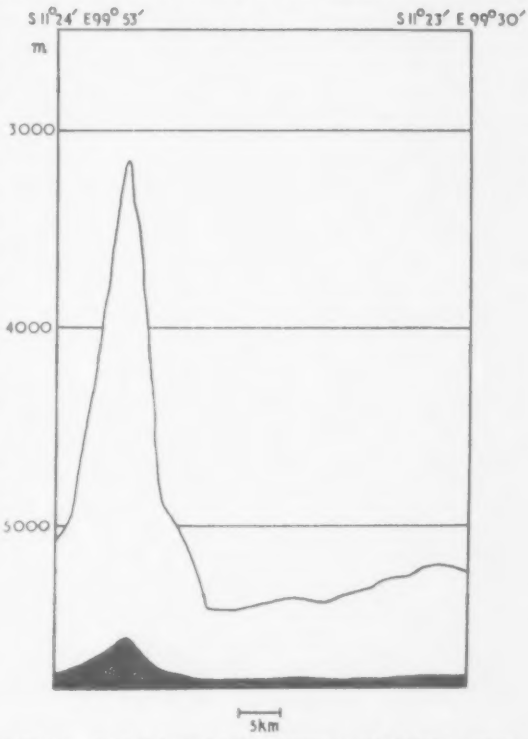

Fig. 12. Profile across a sea mount in the Indian Ocean, see also Fig. 14.

VOLCANOES AND MOUNTAIN CHAINS

For mountains two examples are given. The first (Fig. 9) was recorded on crossing the Carlsberg Ridge in the Indian Ocean. It shows clearly the accumulation of sediment in the deeper part indicated by a nearly horizontal surface. The sediment is supposed to be moved by slumping along the sides of the highs. These flat sediment accumulations are very often found on crossing mountain chains such as the Carlsberg Ridge or the Mid-Atlantic Ridge and also between volcanic islands. The other example is taken from the Atlantic Ocean north of the Romanche Gap showing a part of the Mid-Atlantic Ridge (Fig. 10).

The next group of features seems to be of volcanic origin. In fissures of faults lava gashes out. The surface hardens at once and, shielding the deeper parts from cooling, it may be spread over wide areas. The resulting surface is very rough and many cross overs can be recorded (Fig. 11).

The two following reproductions demonstrate volcanic cones on the sea-floor. Fig. 12 shows a cone with an elevation of more than 2,000 m above the sea-floor with a diameter at the base of at least 20 km. It should be pointed out that the probability of our cutting the top of a volcano was very small, because our track was determined by other considerations than the finding of deep-sea features. Most of the profiles taken during the expedition, therefore, cut the cones of volcanoes more or less outside the centre. The altitude and the diameter are in this way reduced and guyots and sea-knolls cannot be pointed out as the features which have not been adequately surveyed. Some of the cones show steps (Fig. 13), a feature already denoted by KUENEN (1935) in the Snellius Reports.

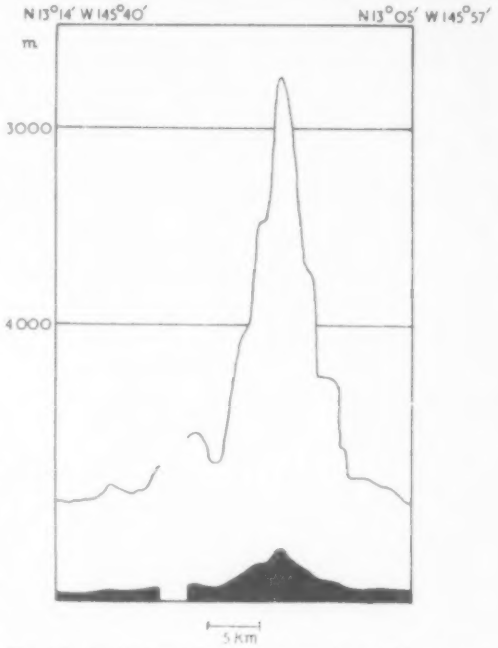

Fig. 13. Profile across a seamount in the Northern Central Pacific.

A PROFILE IN THE INDIAN OCEAN

Finally, a profile is given (Fig. 14), extending from the Java Trench toward 11° 04′ S 88° 35′ E. It was chosen as the region demonstrating most of the dominant features of the deep-sea floor. The track of the *Albatross* is shown on the insert chart, which is drawn after the Bathymetric Chart of the Hydrographic Bureau in Monaco. The parts where soundings have been carried out are marked by full lines. The depth is given in metres and fathoms, the distances in kilometres and nautical miles. The exaggeration is 1 : 20 and 1 : 2, to demonstrate the minor features as well as the real slopes. All depths are correct for sound-velocities and errors of the apparatus. The positions are supposed to be exact within 5 nautical miles.

In the western part of the profile we found an extended plateau with a depth of about 2,000 m. A trench separated it from a mountainous region on a ridge after which toward the east the sea-floor is more or less level. The western part shows a hill district, caused by minor volcanic activity. Then follows a pronounced volcanic region with some typical cones. Between them and the commencement of the dip toward the Java Trench a plain can be seen. Tectonic and volcanic forces seem to be predominant in the whole region. Very seldom could we detect cones of similar dimensions.

CONCLUSION

It must be emphasized that this short study is only an attempt to reach a classification of the deep-sea bottom features on the basis of the forces in action. The sounded profile does not afford an explanation, and other geophysical means must be

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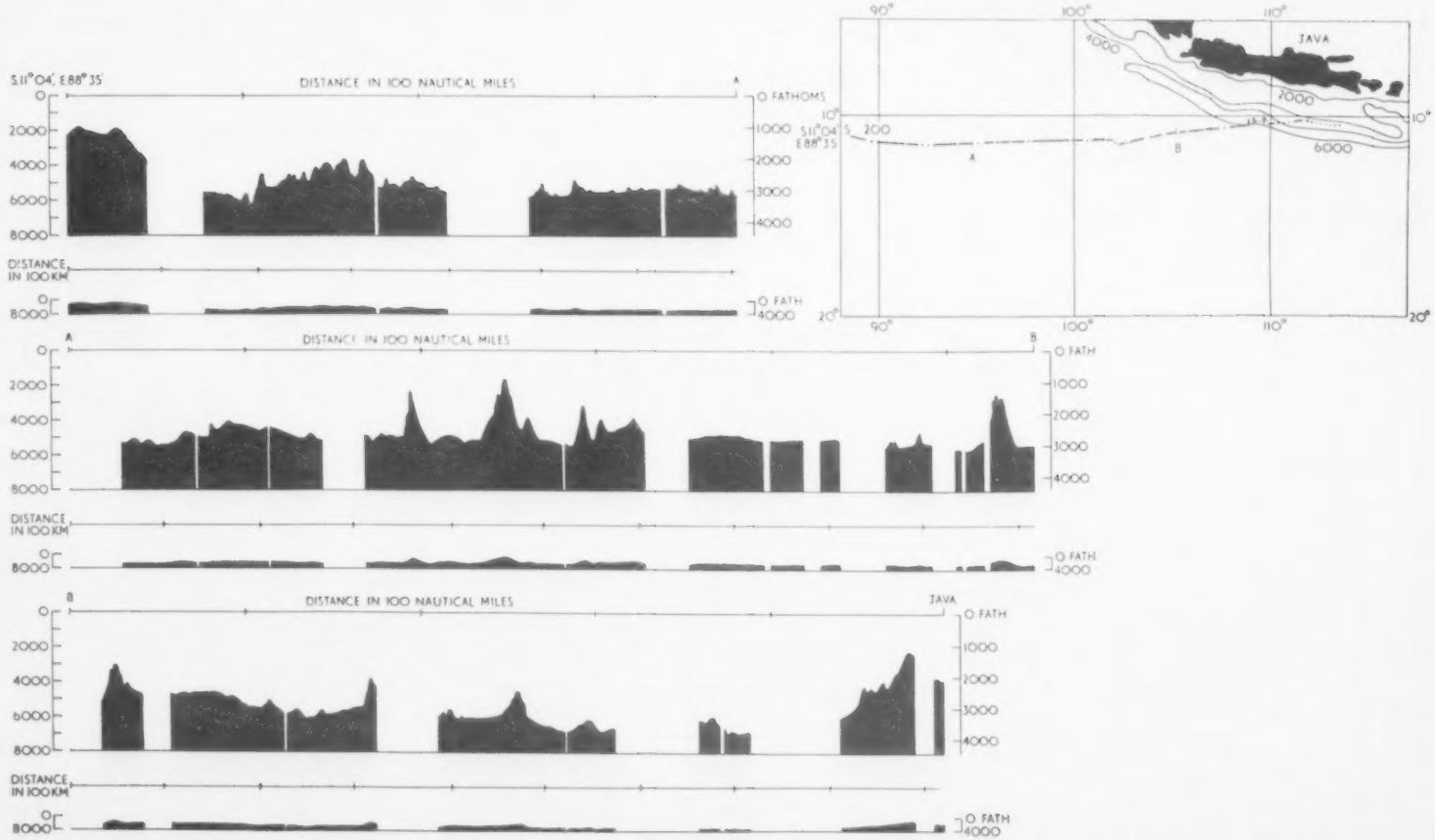

Fig. 14. The echo-sounding section from Java westward. The exaggeration is 1 : 20 and 1 : 2. Depths are given in fathoms and metres, distances in miles and kilometres. The track is shown in the insert chart.

used for a full understanding. However, the three main types of deep-sea features, plains, hill districts and volcanic tectonic regions, are reputed to be a good guide for further geophysical investigation.

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Oceanographic research in the Indian Ocean

RHODES W. FAIRBRIDGE

Summary—Attention is drawn to the increasing activity of oceanography in the Indian Ocean, not only to deep sea expeditions, but also to the formation of a Pan Indian Ocean Science Association which holds its second meeting in Perth, Western Australia in August, 1954. The formation of an Indo-Pacific Institute of Oceanography was formally proposed at the meeting of the UNESCO Panel of Oceanographers, meeting in Manila, November, 1953.

OVER the past twenty years there have been a number of oceanographic expeditions to the Indian Ocean, so that this region is beginning to take its place in the scientific picture of the oceans. The work of the *Dana*, the *Mabahiss* (John Murray Expedition), the Dutch submarine traverses (under Vening Meinesz) the *Albatross*, the *Galathea* and the *Discovery II*, has brought in a great deal of valuable data from the deep seas of the Indian Ocean.

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PANINDIAN OCEAN SCIENCE ASSOCIATION

The time seems ripe therefore to consider a graduation in our approach, in addition to the individual oceanographic expeditions, to the development of an indigenous, shore-based marine research scheme in the southern continents peripheral of this ocean.

Just as the Pacific Science Association and its periodic Congresses in different parts of the Pacific region have, over the past thirty years, contributed greatly to the development of science – and notably oceanography – in that region, it was thought that the regions of the Indian Ocean would benefit from a similar scientific organization. Through the channels of the Australian National Research Council (Western Australian Branch), the writer received the enthusiastic support of Professor A. D. ROSS, O.B.E., chairman of that branch, and by his indefatigable work the scheme has now come to fruition.

The first meeting of this *PanIndian Ocean Science Association* was a formative one, held at Bangalore, India, at the same time as the meeting of the Indian Science Congress Association, in January 1951, and Professor H. J. BHABHA, F.R.S., was made Chairman. Plans were then drawn up to form national committees and prepare for the second meeting which is expected to be a full-scale scientific gathering. The "*Second Science Congress of the PanIndian Ocean Science Association*" is to meet in Perth, Western Australia in August, 1954 with Professor ROSS as the Secretary.

Of particular interest to deep sea researchers are the programmes of Section C (Geology) and Section F (Geography and Oceanography), which are organizing sessions on: "Limits of the Indian Ocean" (a preliminary circular, prepared by the present writer has already been issued), "Directory of Research Personnel" (preliminary list already issued), "Institutes or associations of Institutes of Oceanography," "Gondwanaland Stratigraphy and Tectonics," "Origin and tectonics of the Indian Ocean basin," "Pleistocene deposits in Australia and southeast Asia,"

" The Charnockite problem," a joint meeting of sections A and F will deal with " Indian Ocean soundings and gravity surveys"; and a joint meeting of B, F, and G will attend to " Fisheries – pelagic, demersal, and fish farming."

OCEANOGRAPHIC ORGANIZATION FOR INDO-PACIFIC

With regard to the question of " Institutes or Association of Institutes of Oceanography," this was discussed from the P.I.O.S.A. viewpoint by Dr. K. SHEARD, committee convener for Section F, with the writer and Dr. D. ROCHFORD (as Australian members of the U.N.E.S.C.O. Panel of Oceanography), and the subject was brought up at the recent meeting of this U.N.E.S.C.O. panel at the time of the Pacific Science Congress at Manila, November, 1953.

The U.N.E.S.C.O. Panel of Oceanographers has now agreed that a new organization is needed for fundamental oceanographic research in the Indo-Pacific region. This was to be quite distinct from the existing Indo-Pacific Fisheries Council, and should be sponsored jointly by U.N.E.S.C.O. and F.A.O. It is too early yet to make a definite statement regarding this proposal, but enough is reported here to indicate the very generally rising interest in oceanographic research in the Indian Ocean.

University of Western Australia

Temporarily: *University of Illinois, U.S.A.*

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GEOLOGICAL NOTES

ENIWETOK DRILLING RESULTS

PRELIMINARY results of the Eniwetok drillings have been reported by LADD *et al.* in the October issue of the *Bulletin of the American Association of Petroleum Geologists.* The writer would like to offer two comments.

(1) The drillings obviously lend strong support to DARWIN's theory of subsidence. But in my opinion they can only be explained satisfactorily by assuming the added result of glacial control.

To account for the properties of atolls and barrier reefs I suggested some years ago that slow Tertiary subsidence of the foundations produced barriers and atolls without passages. This development was followed by low-level chemical decapitation in the Ice Age. In post-glacial (and inter-glacial) time the reefs grew up at great speed following the swiftly rising sea level. As a result of this haste many gaps were left in the reef-rims. The main arguments are the absence of deep passages (KUENEN, 1947, 1950) and the absence of double or multiple barriers (KUENEN, 1951). If present reefs with their passes were to subside these gaps would remain and gradually attain great depths. They must be a newly developed feature of the coral seas, because there are practically no passes deeper than glacial sea level. According to DARWIN's postulates the frequent fringing reefs now present within barriers must develop by future subsidence into inner barriers (Fig. 1). As such double barrier reefs are absent, the combination we now see did not exist formerly and must be attributed to some recent abnormal happening. Evidently it was glacial control which created favourable conditions for corals within the lagoons, mainly by developing passes and improving ventilation.

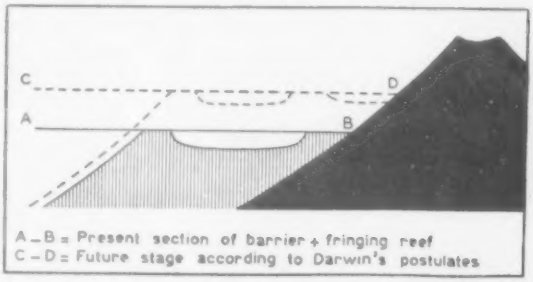

Fig. 1. Development of a double barrier if a fringing reef and barrier grow upwards according to DARWIN's postulates.

Hence, it follows that the swift post-glacial rise of sea level is the main factor involved in producing both the gaps in the reefs and the fringing reefs within barriers.

The postulated slowness of the Darwinian subsidence is now confirmed for Eniwetok. The top of the Miocene lies at 600 feet depth, indicating a subsidence of 50 to 60 feet per million years. The top of the Eocene is at 2,800 feet, corresponding to a subsidence of some 60 to 70 feet per million years. Dredgings on guyots give figures of the same order of magnitude. Erben Guyot 2,400 feet in at least 20 million years, that is at most 120 feet per million years (CARSOLA and DIETZ, 1952); Mid-Pacific guyots 5,500 feet in about 80 million years, that is 70 feet per million years. Roughly the subsidence of the drilled and dredged seamounts works out at 2 cm per 1,000 years.

Long ago MOLENGRAAFF suggested that the subsidence required by DARWIN's theory might be the result of isostatic sinking of volcanic cones. That volcanic cones actually form a burden on the crust has now been established in several instances (e.g. VENING MEINESZ, 1948; WOOLLARD, 1951). The objection could be raised that the glacial isostatic adjustments are about one thousand times as swift. However, the reason for this difference is that in the case of land ice the load far exceeds the strength of the crust so that the viscosity of the substratum is the limiting factor for the speed. In the case of a volcano the crust carries the load, but under the constant stress a very slow adjustment is apparently brought about by " recrystallization and slippage along crystal glide planes " (CARSOLA and DIETZ, 1952, p. 495) and by occasional faulting. This is an entirely different process and, logically, is much slower than plastic flow of the substratum. The counterpart is formed by the slow rise of the Moluccan islands lying on the belt of negative anomalies, where elevation has averaged about 10 cm per 1,000 years.

The Eniwetok cores comprise zones, with corals and molluscs preserved as moulds. LADD *et al.* interpret these as indicating periods of emergence. They point out that " Comparisons with zones

of moulds in other drill holes may indicate whether the changes were local or eustatic " (p. 2278). In the view put forward here that the foundations are sinking by their own weight, it seems highly unlikely that the subsidence was interrupted by elevation. Hence the emergence, if it did actually occur, should prove to have been caused by mild pre-glacial eustatic movements.

In contrast with the Tertiary subsidence of one or two centimetres per 1,000 years glacial eustatism, on the other hand, attained roughly 400 cm per 1,000 years as an average and considerably more for part of the time. If the reefs had been beheaded or at least severely breached during low sea levels, the rapid drowning during the rise of sea level would account for the development of passages.

Now it is stated in the Abstract of the Eniwetok paper that: " Each hole penetrated several hundred feet of soft, Quaternary reef limestone before entering a thick, Tertiary, section of similar rocks."

Assuming the age determination to be correct, the average rate of upgrowth for the whole Quaternary is about ten times that for the Tertiary. It is highly improbable that the subsidence of the foundation has been so much faster during the last 2 or 3 per cent of the time represented by limestone deposition. This improbability is rendered even less acceptable by the fact that a similar increase is indicated by the Bikini bore hole.

The alternative is to attribute the sudden change in rate of accumulation to the operation of an entirely different process, for the two periods involved, namely glacial eustatism instead of subsidence. However, this implies that the late-Pliocene reefs have been greatly reduced, or even entirely cut off, at low sea level. Their surfaces, if not destroyed, would probably have lain some twenty metres above present sea level, assuming they grew to sea level on an ice-free world about + 120 ft. or more (AHLMANN, 1952) one million years ago. If severe attack during the first ice age is admitted, the last lowering must have wrought at least equal havoc. Probably there was even some cumulation of effect. This means that the reefs had to start rebuilding after the last Ice Age, some 25,000 years ago, almost from scratch or at least from a reduced ruin, constructing the present reefs at 200 times the vertical rate of pre-glacial times. However, estimates of the rate of reef upgrowth do not render this feat in the least bit improbable.

This picture is confirmed by the absence of emerged inter-glacial rims. These should logically have grown up to inter-glacial sea level just like the post-glacial rims have managed to reach present sea level. But those inter-glacial reefs have evidently been degraded to well below the present surface of the oceans.

The borings now bring another significant piece of evidence in support of this glacial control. Every emerged reef, whatever the climate, is consolidated and recrystallized in a minimum of time. Field evidence to this effect has accumulated from all over the coral seas. Either a massive and firm reef rock or a cavernous but hard crystalline mass is developed. There would have been opportunity many times over for this process during the repeatedly lowered sea level of the Ice Age.

The absence of well consolidated rock above glacial sea levels in the Eniwetok and Bikini borings therefore can hardly be attributed to failure of the reefs to consolidate and recrystallize during emergence. A much more satisfactory explanation is to assume that solution has removed the bulk or even all rock above the lowered sea levels, thus leaving little trace of the consolidation which must have taken place.

Summarizing, two new arguments are presented testifying to the action of glacial control, viz. (1) absence of consolidation in the upper few hundred feet showing that the present rims grew up after the last low sea level, and (2) abnormal rapidity of upgrowth during the last phase of atoll growth. If accurate datings of core samples could be made it should be found that the upper 120 metres is mainly post-glacial resting on material deposited about 7 million years ago (assuming sea level of the late Pliocene to have been 40 metres above present sea level and 20 metres subsidence of the foundation since then). In other words the Upper Pliocene part of the column was destroyed by glacial control. For further arguments the reader is referred to earlier papers (KUENEN, 1947, 1950, 1951). If decapitation during the low sea levels has been less complete this picture is modified accordingly.

(2) The clay size calcareous matter encountered in some parts of the Eniwetok bore holes is apparently very similar to that of the soft chalky limestone found in the core put down by the *Bataafsche Petroleum Maatschappij* on Maratoea (KUENEN, 1947, p. 9-11). The explanation offered for the Indonesian example can perhaps be applied to the Pacific atoll also. I suggested that passages

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in atolls are an abnormal feature developed by glacial eustatism (see foregoing comment, and KUENEN, 1950, p. 467). The unbreached rims of Tertiary atolls created poorly ventilated conditions in the lagoons suitable for the precipitation and accumulation of calcium carbonate. This precipitation is absent from most recent lagoons because of ventilation. Its place is taken by *Halimeda*, Foraminifera, corals, etc. This hypothesis should be tested by the investigation of some well closed present day lagoons.

In conclusion I would like to emphasize the tentative nature of the above remarks. They are intended to stimulate enquiry more than to mark final results.

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LETTERS TO THE EDITORS

New evidence that migrating gas bubbles, probably the swimbladders of fish, are largely responsible for scattering layers on the continental rise south of New England

PROBLEMS in scattering layer research were discussed at the Woods Hole Oceanographic Institution in a series of weekly meetings during the summer of 1953 by staff members and other interested scientists. Among the methods suggested for identifying components of scattering layers one appeared immediately applicable for testing the hypothesis that fishes with swimbladders are important constituents of some layers. Mr. A. C. VINE proposed that acoustical records be examined for the shifts in resonant frequency of scattered sound that should be observed as swimbladders contract and expand during vertical migrations.

Data for this examination were recorded from the R/V *Bear* on the 23rd and 24th of August, 1953 at 39°42'N, 70°20'W on the continental rise south of New England where the water depth was about 1,100 fathoms. Recordings were made roughly every three minutes for 1 and ½ hours starting ½ hour before dawn and using techniques essentially similar to those described by HERSEY, JOHNSON and DAVIS (1952). These employ an explosion as a sound source and a directional receiver pointing downward. The sounds received in the present work were recorded on magnetic tape through an electronic system having flat response from 50 to 15,000 cps, and were analyzed on a Kay Electric Company Vibralyzer following the " visible speech " techniques described by KOENIG, DUNN and LACY (1946). By reproducing the tape recorded sounds at one-fourth the original tape transport speed analyses covering the full range of the original recording were obtained. The Vibralyzer records are three dimensional displays of the scattered sound in which frequency and travel time of the sound are the two plane coordinates and relative intensity is shown by relative blackening of the teledeltos paper on which the Vibralyzer records, thus giving a plot of sound scattering as a function of depth and frequency when due allowance is made for the directional properties of the receiver.

Analysis of these recordings confirmed the earlier findings of HERSEY, JOHNSON and DAVIS (1952) that there are several scattering layers having peaks of scattering power at different frequencies. They showed further that the peak frequencies increase as the layers descend at dawn in a manner roughly proportional to the first power of the depth. So sensitive a variation with depth suggests a highly compressible scatterer such as a gas bubble. The analysis is too crude to distinguish between the first power of the depth and the 5/6th power, which would be the manner in which the peak frequency of a migrating gas bubble would vary with the hydrostatic pressure. On the assumption that this constituted good enough agreement with the gas bubble theory, we computed the diameter and volume of the corresponding gas bubbles at one atmosphere for the three most prominent peaks. These are 16·7, 5·5, and 1·9 millimetres and 4,700, 165, and 6·5 mm^3 respectively. The first two can be identified with layers that have midday depths of approximately 400 and 300 metres respectively. The midday depth of the third is unknown because its frequency increases to some point beyond the upper limit of our recorders. This occurs rather early in the migration period when its depth is about 180 metres.

This range of sizes falls within those given by MARSHALL (1951) for the swimbladders of common bathypelagic fishes. The 6·5 mm^3 volume agrees rather closely with those reported for *Myctophidae* (lanternfishes). For instance, choosing the commonest lanternfish collected by the *Blue Dolphin* in the same area for which evidence of extended vertical migration was shown (*Diaphus dofleini* Zugmayer), a volume of 11·1 mm^3 is computed for its swimbladder using the dimensions given by MARSHALL for this species. The length of MARHSALL's specimen approximated the mean length of our material. The evidence thus suggests that scattering peaks observed in this area are due to the swimbladders of fishes and that the sea level volume of their swimbladders are approximately given by the gas bubble volumes above. In making this suggestion we are disregarding the departure of the swimbladder from a spherical shape since its shape under the conditions of observation is unknown. We also disregard for the present questions of the size distribution in the population causing a single scattering peak. The collections of the *Blue Dolphin* in this area include many

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fishes larger than lanternfishes (mainly bathypelagic eels and stomiatids) not yet examined which may have swimbladders of a volume the order of 165 mm^3. The gear used was not appropriate for collecting fishes of such size that their swimbladders would approximate the greatest volume computed, 4,700 mm^3.

The scattering layers in this area have long been known as strikingly more intense than in many other parts of the western North Atlantic, and it is evident that the scattering peaks that have just been described do not comprise all the sound scattered by material in the water. Hence these results are a strong indication that migrating gas bubbles, probably the swimbladders of fishes, are responsible for a large part of the sound scattering in this area, but any suggestion that they are the sole cause of the deep scattering layers is unwarranted.

We are indebted to Miss CONSTANCE HINDLE for carrying out the Vibralyzer analyses and to the several members of the field party who assisted in the observations. This work was carried out under contract NObsr-43270 with the Bureau of Ships, U.S. Navy Department.

Woods Hole Oceanographic Institution J. B. HERSEY
February 18, 1954 R. H. BACKUS

Contribution No. 676 of the Woods Hole Oceanographic Institution

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DISCUSSION

Discussion on papers presented at the Symposium of the Joint Commission on Oceanography at Liverpool, 1-2 September 1953, by Dr. F. Koczy and Professor C. W. Correns

Dr. Koczy

My conclusions on the Ti distribution in the deep-sea was made from a statistical point of view. I could show that there exists a very good correlation between the total sedimentation and that of titanium, but of course there is a high scattering and the given Ti content is only an average value. But in this way I could show that a considerable part of the sediment must be titanium free material, which was supposed to be silica material of organic origin.

I could only use the values given by Professor Correns for the surface of the sediment as no other determination of Ti in the post glacial sediment were available at that time. But, I think, that the origin and hence the composition of the sediment have not been changed considerably in this short period. Of course no others than mean values could be obtained; it can not be allowed to draw conclusions of the rate of Ti sedimentation for all cores and all periods, when only the sedimentation rate of Ti in one single core is known and there only for a short period of time.

Prof. C. W. Correns

Mit dem letzten Satz von Dr. Koczy's Bemerkungen, dass es nicht möglich ist, auf Grund seiner statistischen Untersuchung Schlüsse auf die Sedimentationsgeschwindigkeit eines einzelnen Lotkernes zu ziehen, bin ich vollkommen einverstanden. Gegen die statistische Methode, die Herr Dr. Koczy angewandt hat, sind folgende Einwände zu erheben: Dr. Koczy hat nur den Titangehalt der Oberflächenproben behandelt, da nicht genug, nämlich nur 18, Titanbestimmungen in postglazialen tieferen Schichten vorliegen. Immerhin zeigen diese 18 Proben, dass bereits in der Postglazialzeit erhebliche Schwankungen im Titangehalt auftreten, die, wie die im Anhang migeteilte Tabelle an zwei Beispielen zeigt, nicht etwa mit dem Gehalt an Kieselorganismen erklärt werden können. Die Arbeitshypothese eines konstanten Titangehaltes der terrigenen Bestandteile ist also schon für die Postglazialzeit nicht zu halten, erst recht nicht für noch ältere Schichten. Beschränken wir uns auf die Oberfläche, so gibt die statistische Behandlung hier einen Mittelwert, der aber nur dann für die Sedimentationsuntersuchungen Bedeutung haben würde, wenn sich der einzelne Beobachtungswert zufallsmässig um einen festen Wert gruppieren würde. Aber für die Sedimentation ist es gerade wichtig, die Titanwerte nicht als solche zufälligen Abweichungen anzusehen sondern zu versuchen, die Ursachen dieser verschieden hohen Titangehalte in den verschiedenen Teilen der Meeresbodenoberfläche genetisch zu erklären.

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Further evidence for a turbidity current following the 1929 Grand Banks Earthquake

BRUCE C. HEEZEN, D. B. ERICSON and MAURICE EWING

Summary—Evidence has been obtained indicating that the uppermost layer of sediment of the abyssal plain south of the Grand Banks consists of silt and sand. The top layers of two piston sediment cores consist of 130 and 70 cm of graded silt and sand overlying foraminiferal clay of abyssal facies. Recent deposition of these graded layers is indicated by absence of abyssal sediment overlying them. At three additional coring stations nothing but a few grains of sand was obtained.

The existence of this silt and sand layer constitutes a further line of evidence in support of the hypothesis of HEEZEN and EWING (1952) that slumps initiated by the 1929 Grand Banks earthquake were transformed into a turbidity current which swept down slope, broke and carried away the submarine telegraph cables, destroyed bottom life and deposited a large quantity of sediments far out into the ocean basin.

The thickness of the graded silt and sand layers in the cores is near to the 40-100 cm thickness predicted by KUENEN (1952).

The existence of the layers of silt and sand is also further evidence for the hypothesis that the abyssal plains with their flat gently sloping surface were formed by ponded or otherwise spent turbidity currents.

INTRODUCTION

IN the following paper a description and discussion of the sediments obtained at five coring stations south of the Grand Banks is offered as a new line of evidence in support of an hypothesis offered by HEEZEN and EWING (1952) in explanation of certain facts related to the 1929 Grand Banks earthquake. This earthquake of magnitude 7½ shook the Continental Shelf and Slope south of Newfoundland on November 18, 1929. All submarine telegraph cables in the epicentral area were broken instantly at the time of the quake. During thirteen hours following the quake five other cables lying in deeper water south of the epicenter were broken in orderly sequence from north to south. The times of the breaks were accurately recorded by the machines which receive messages and their positions determined by resistance measurements made from each shore end. During the next twenty years various attempts were made to explain the delayed breaks, but no satisfactory explanation was found. Recently HEEZEN and EWING (1952) proposed that the delayed breaks were due to a turbidity current ; a torrent of water made dense by suspended sediment. According to this theory (Fig. 1) the quake set in motion slides and slumps of unconsolidated sediment at various points within about 40 miles of the epicenter on the continental slope. These moving masses of sediment either by addition of more and more water or by loss of their thixotropic strength (KUENEN 1952) rapidly became true turbidity currents which converged to form a great flood of turbid water rushing down the continental slope, continental rise and across the abyssal plain breaking the cables as it reached them.

The velocity of the current determined by the time intervals and distance between succeeding breaks decreased with decreasing slope as indicated in Fig. 1. When the current had broken the last cable the turbidity current still had a velocity of 12 knots after flowing about 150 miles on the abyssal plain down a slope of only 1 : 1,500.

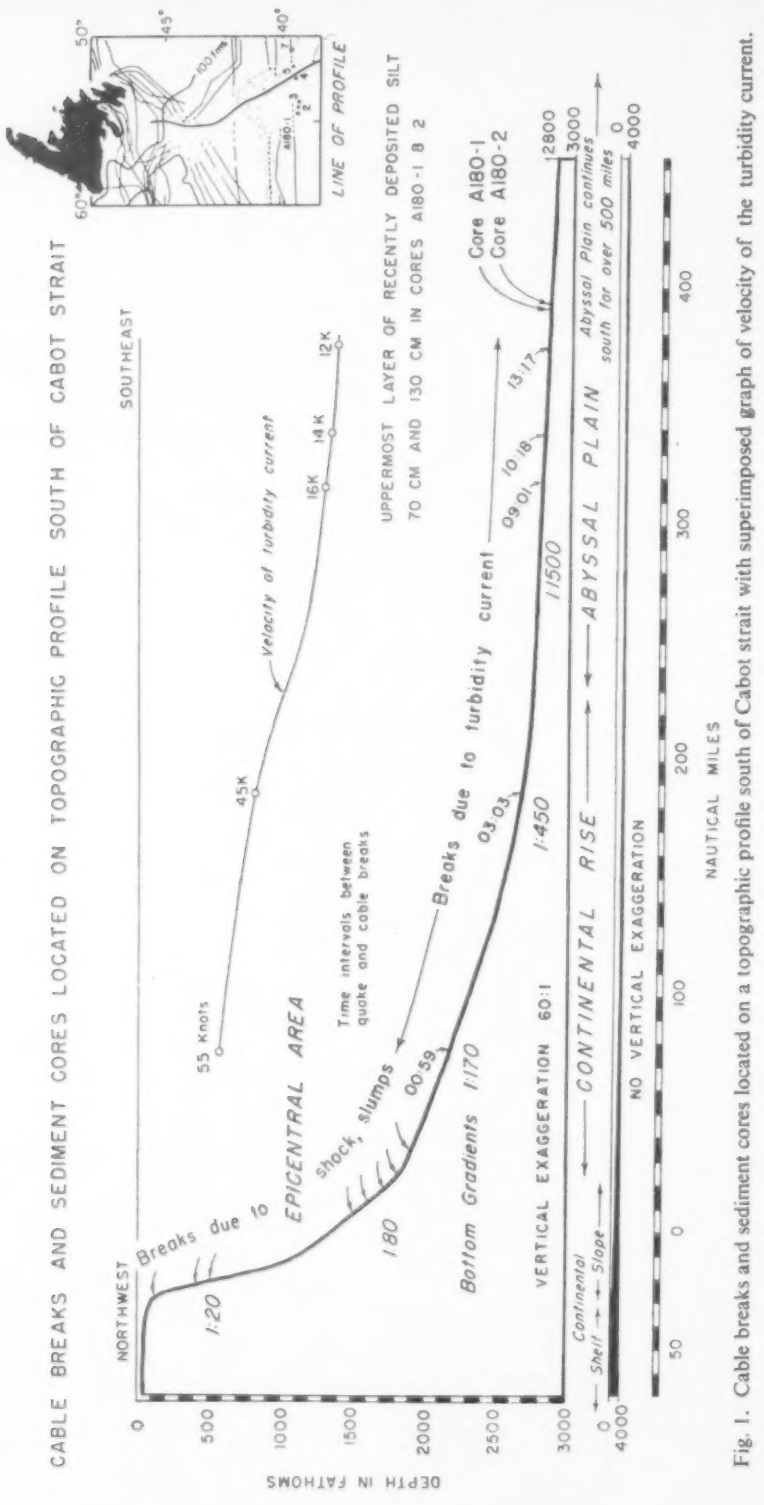

Fig. 1. Cable breaks and sediment cores located on a topographic profile south of Cabot strait with superimposed graph of velocity of the turbidity current.

KUENEN (1952) computed the size of the current and the amount of sediment involved from the velocities found by HEEZEN and EWING (1952) and concluded that the predicted bed of fine sand and silt deposited on the abyssal plain south of the cable breaks " might show up . . . over an area of perhaps 100,000 square miles " and " the average thickness would be 40-100 cms."

At the time HEEZEN and EWING (1952) and KUENEN (1952) wrote no core samples had been taken in the area. Knowledge of the sediments of the area was limited to descriptions of samples scraped from the grapnels used by the cable repair ships. KINDLE (1931) described about two dozen such samples of gravel, sand and clay from the epicentral area. In a study of the repair ship reports HEEZEN and EWING (1952) found a few references to " sharp sand and small pebbles " found near the southermost cable.

From the start it was obvious that cores from the region to the south of the cable breaks would be of great importance. If a graded sand or silt layer was found on top its occurrence would constitute strong evidence in support of the turbidity current hypothesis. Once found, an adequate sampling of the bed could furnish the basic data to establish fundamental characteristics of turbidity currents. In both 1950 and 1951 the research vessel *Atlantis* was on her way to the area when hurricanes forced her to abandon the project and run to safety. Finally in 1952 HEEZEN lowered the piston coring tube six times along an east west line on the abyssal plain just south of the southern-most cable (Fig. 1, 2 and Table 1).

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Table 1.
List of Core Stations July 24 *and* 25, 1952 *on Atlantis Cruise* # 180 *with* 1,100-*lb. Piston Core.*

Core No.	*Lat.*	*Long.*	*Depth*		*Length*	*Remarks*
			Fms.	*Meters.*	*cms.*	
180-1	39°07½N	54°32½W	2840	5190	70	Pipe badly bent in four places. See Fig. 2.
180-2	39°06N	54°11W	2840	5190	130	Pipe badly bent four feet from bottom. See Fig. 2.
180-3	39°08N	53°54′	2840	5190	Neg	Pipe bent three feet from bottom. A few grains of sand.
180-4	39°19′	52°31′	2840	5190	Neg	Pipe bent three feet from bottom. A few grains of sand.
180-5	39°30′	51°48′	2860	5230	Neg	Pipe bent. A few grains of sand.
180-7	39°36′	50°51′	2860	5230	123	—

DESCRIPTIONS OF THE CORES

At two stations A180-1 and A180-2 cores 360 and 100 cms in length contained an uppermost graded well sorted silt layer 130 and 70 cm thick which in each case lies with a sharply defined base on foraminiferal brown lutite of abyssal facies. At 3 stations (A180-3, 4 and 5) the coring tube brought up only small samples of sand.

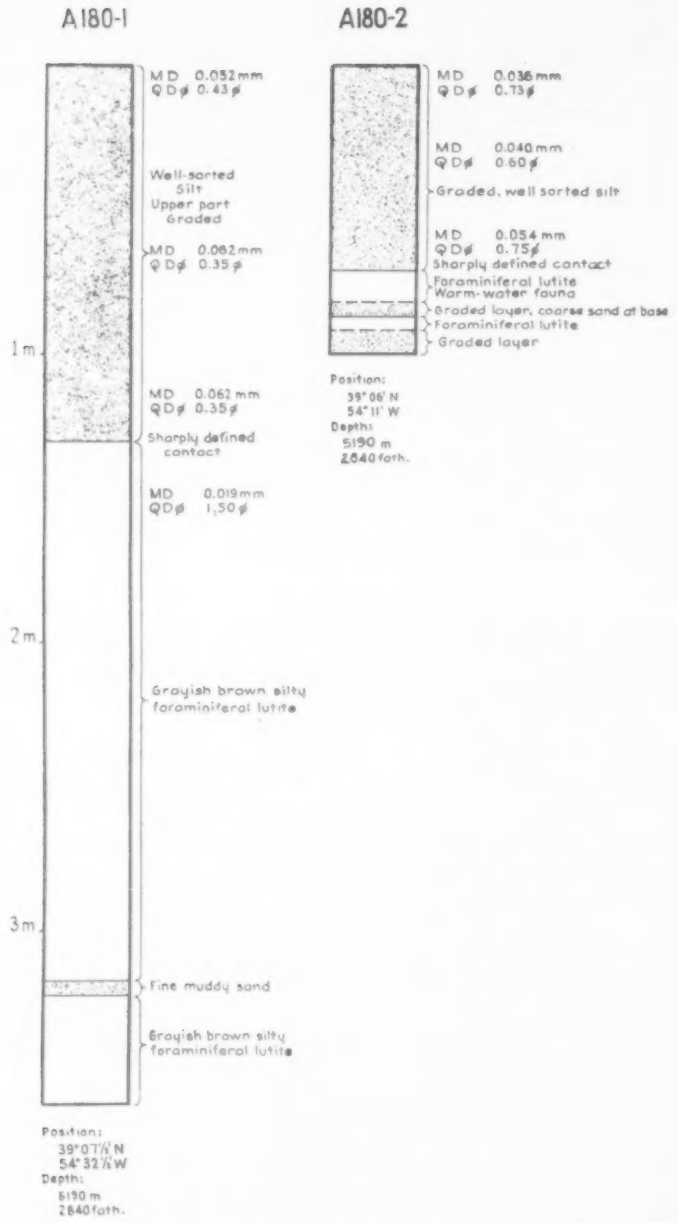

Fig. 2. Logs of cores 180-1, 180-2 from the abyssal plains south of the cable breaks.

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In all 5 cases the coring tube was badly bent and the cutting edge was polished. It is probable that at the 3 stations clean sand was encountered which limited the penetration of the coring tube to a few feet, and that the sand was lost through the " core-catcher."

Stations A180-1 and A180-2 lie about 15 miles apart and about 15-20 miles south of the southern cable in a depth of 5,200 metres (2,850 fathoms) on the abyssal plain. It is of the greatest significance that the upper part of each of these cores is a well sorted silt lying on foraminiferal brown lutite of abyssal facies. The thicknesses of silt are 130 cm and 70 cm. There is no evidence of normal deep-sea sediment on the silt. However, since the tops of long cores are usually somewhat disturbed in transportation to the laboratory, a thin layer of lutite could easily have been lost. The important thing is that the thickness of such a layer overlying the silt was probably in the order of a few millimetres rather than a few centimetres. The basal contacts of the silt

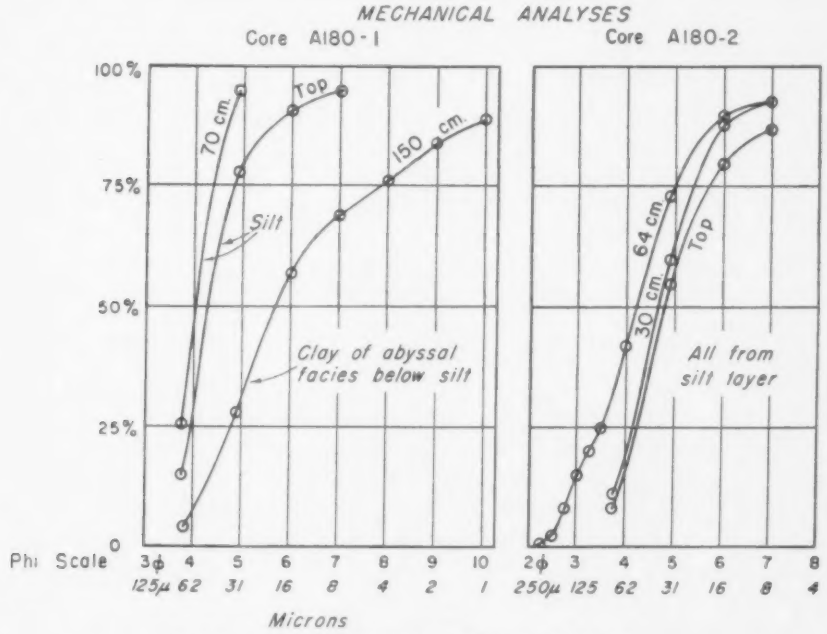

Fig. 3. Mechanical analysis of cores 180-1 and 180-2.

layers are sharply defined. Mechanical analyses (Fig. 3) of samples of the silt show that it is well sorted, the quartile deviations in phi units varying from 0·35 to 0·75. In contrast, the abyssal sediment below the silt in core A180-1 has a quartile deviation of 1·50. The cumulative curves also show that the layers are graded, or that there is increase in median diameter with increase in depth within the layer. In A180-2 the median diameter increases from 0·036 mm at the top to 0·054 mm near the bottom of the layer. In A180-1 there is an increase in median diameter from the top to 70 cm but below that depth both median diameter and quartile deviation remain constant. Quartz is the dominant mineral of the silt but various feldspars, micas, dark minerals and glauconite are also present in abundance. About five per cent

of the quartz and feldspar particles are stained red by iron oxide. Shards of volcanic glass are present but very rare. Shells of small foraminifera and broken sponge spicules are abundant, but no large shells of Globorotalia are present. It is noteworthy that the shells and spicule fragments are well sorted and conform to the cumulative curves of the mineral particle sizes.

The sediment below the silt is a poorly sorted silty lutite containing relatively large shells of planktonic species of foraminifera in abundance. The section below the silt in A180-1 is fairly uniform except for a 5 cm layer of muddy sand 320 cm below the top. In the corresponding section of core A180-2 there are two graded layers, 5 and 9 cm thick. Both grade from well bedded silty lutite at the top downward into very coarse sand composed of subangular particles of red shale, red and gray sandstone, limestone, metamorphic rocks, and a minor fraction of quartz and feldspar particles. The reasoning applied to the silt above applies equally to these two layers. The only satisfactory explanation appears to be deposition by turbidity currents. The thickness of normal slowly deposited sediment between the base of the silt and the top of the graded layer below indicates a fairly long interval of time, hardly less than several hundred years, between the catastrophe responsible for its deposition and the time of the Grand Banks earthquake. A still more remote time of deposition is indicated for the lowest graded layer.

Another core, A180-7, was taken from a depth of 5,230 metres (2,860 fms) at a point about 160 nautical miles east of the two just described, and a short distance east of the area in which the cables were broken. Unlike the other cores the upper part of this to a depth of about 30 cm is a brown foraminiferal lutite of abyssal facies. Below 30 cm gray lutite very gradually grades downward into well sorted silt between 95 and 100 cm. The upper contact of this graded layer with the brown lutite is indefinite and blurred by the burrowing of mud-feeding animals. The lower contact, however, is very sharply defined. The sediment below the graded layer is dark gray foraminiferal lutite. Although the upper part of this lower 23 cm layer is of normal deep-sea facies, the lower part appears to be fairly well sorted and may represent the upper part of another graded layer.

The only satisfactory explanation for the graded layer is deposition by a turbidity current. However, the thickness, 30 cm, of the overlying normal or unsorted sediment containing the shells of large planktonic foraminifera shows that the time of deposition of the graded layer must have been long before that of the Grand Banks earthquake.

Although the rate of accumulation of deep-sea sediment varies somewhat from place to place depending upon bottom configuration, investigation of hundreds of cores in the collection of the Lamont Geological Observatory has shown that the most rapid rate of pelagic sedimentation does not much exceed 1 cm in 100 years. The graded layer, therefore, was probably deposited some thousands of years ago.

DISCUSSION OF NEW EVIDENCE

Thus far we have summarized the hypothesis of a turbidity current following the 1929 Grand Banks earthquake, quoted estimates pertaining to the thickness of the resulting deposit and told of searching for and finding a silt layer of the predicted thickness in the supposed area of deposition. Could the silts be explained in some other way then by deposition by a turbidity current ? Since deep sea sands were first discovered in 1876 several different theories of their origin have been proposed.

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Perhaps one of these explanations could satisfactorily explain the silt layers in the two cores.

Ice rafting undoubtedly accounts for a large quantity of coarse sediments carried to deep water but such glacial marine deposits are notoriously unsorted. Analysis of the particle size distribution of the silt layers (Fig. 3) shows the good sorting of the silt in contrast with the poor sorting of the abyssal sediment underlying the silt. This grading is good evidence of deposition from a current of decreasing velocity, and certainly not what we would expect if the silts were laid down little by little over a rather long period of time.

It could be argued that the cable break data could be as well explained by a mud flow as by a turbidity current. However it is evident from the grading in the cores that the individual particles of silt were able to settle out of suspension independently. They could not have done so if the material had travelled as a mud-flow. Shells of foraminifera and broken sponge spicules are abundant in the silt. It is significant that the wheels and spicule fragments are as well sorted as the mineral particles. No large shells of *Globorotalia* such as are abundant in the abyssal sediment are present in the silts. In fact the mineral particles, the foraminifera shells, and the spicule fragments in any single sample of the silts have the same mean " equivalent radius," that is, a current strong enough to transport the mineral particles could also transport the shells.

One more thing to be considered is whether the silt could be a product of winnowing by some kind of bottom scour. It is true that many, if not all, of the mineral species in the silt also occur in the abyssal sediment below the silt. However, many samples of the coarse fraction from the abyssal sediment concentrated on fine mesh sieves in the laboratory show that the abyssal facies if winnowed would not yield a sediment at all resembling the silt. For one thing the shells of foraminifera would dominate over mineral particles in the winnowed sediment ; for another, the shells would be unsorted. Large shells of *Globorotalia menardii* would be abundant, while they are absent from the silts. There seems to be no explanation of the silts layers which explains them as well as turbidity current. In fact no other presently known process seems acceptable.

The points at which the cables were broken were determined by resistance measurements from shore. All of the cables broken by the turbidity currents were severed at two points separated by 45, 90, 180, 130 and 100 miles. In each case the segment of cable between the two breaks was not found by the repair ships and presumably it was carried down slope and buried (DE SMITT 1932). By grappling back and forth across its known route the repair vessels found each cable at 20, 20, 15, 45 and 30 nautical miles east of the eastern break and 20, 50, ??, 30 and 100 nautical miles west of the western break. As the repair engineers suspected probably most of the cable between the points of recovery and the break was covered by a thickness of sediment exceeding the depth of penetration of the grapnels. In this marginal zone the turbidity current apparently had insufficient energy to break and carry away cables as it did in the central zone but had sufficient energy to carry and later deposit enough sediment to bury the cables. The coring stations are shown in Fig. 4 in relation to the 2 zones just mentioned. Cores A180-1 and A180-2 lie in the marginal zone west of the central zone traversed by the destructive current. Core stations A180-3, A180-4 and A180-5 lie in the central zone and core A180-7 lies immediately

east of the eastern marginal zone. At core stations A180-1 and A180-2 the coring tube completely penetrated an upper layer of graded silt 130 and 70 cms thick and obtained cores of the abyssal clay beneath. At stations A180-3, A180-4 and A180-5 the coring tube entered but presumably did not completely penetrate an uppermost layer of sand. Only a few grains of sand remained in the coring tube at each of the three stations. If the sand had been completely penetrated a core of clay beneath

50°
45°
40°
35°
60°
50°
Abyssal Plain
NE. Bermuda Rise
W. MAR
EXPLANATION
Piston core stations ATLANTIS cruise A180
Submarine telegraph cables
Area of slides and slumps near epicenter
Area travelled by destructive turbidity current. Cables broken and removed.
Marginal area of weaker current Cables buried but not broken
100 fathom contour
Abyssal Plains
Hills and mountains Bermuda Rise, Western foothills of the Mid Atlantic Ridge
THE 1929 GRAND BANKS TURBIDITY CURRENT
Showing relative position of sediment cores and turbidity current

Fig. 4. Chart of current showing areas of cable breakage and cable burial in relation to the cores.

would have served as a plug to prevent the sand from flowing out through the " leaves " of the "core catcher." Core A180-7 containing an uppermost layer of abyssal sediment was obtained east of the eastern marginal zone. As the current reached the southernmost cables the marginal zones of deposition and little destruction were becoming wider and the central zone of destruction was becoming narrower. This is what should be expected of a current running over a nearly level plain having expended a large proportion of its energy. The velocity of the current when it laid down the silt layers found in the two cores was probably considerably less than the velocity of 12 knots calculated for the current which broke the last cable. However,

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the current as it passed over the points where stations A180-3, A180-4 and A180-5 were made must have had a velocity only slightly less than that calculated for the last cable.

The fact that the turbidity current broke and carried away segments of cables indicates that it was erosive in the central zone. Whether the current was erosive in the marginal zone is problematical. Foraminiferal studies on the lutite lying beneath the silt though inconclusive may indicate that some material was removed before the silt was deposited. A sample of the foraminiferal lutite has been submitted for radiocarbon dating. A C-14 date on the sample should determine if any appreciable thickness had been removed before the silt was laid down.

HEEZEN, EWING and ERICSON (1951) concluded that it was very probable that the abyssal plains were formed by successive turbidity currents which buried the small relief features under a flat cover of sediment. Further evidence in favour of this hypothesis was published by ERICSON, EWING and HEEZEN (1952). However, the evidence from the cores described here is perhaps the most impressive of all. Here in historical time a turbidity current of known extent and velocity deposited a layer of about 1 m thickness on a wide area of the abyssal plain.

CONCLUSIONS

The theory was put forward (HEEZEN and EWING 1952) that the successive cable breaks following the Grand Banks earthquake could be satisfacorily explained by supposing that they were caused by a turbidity current. As a corollary it was predicted that an extensive deposit of sand and silt would lie on the abyssal plain to the south of the cable breaks as well as over the more southerly cables.

KUENEN (1952) calculated from the indicated velocities, slope of the bottom, and probable density of the current that the graded well sorted deposit left by the current would have an average thickness of between 40 and 100 cms.

A graded layer of about the predicted thickness has now been found. The cores which contained a graded silt layer lie to the west of the probable path of the most destructive current. Cores attempted within the area transversed by the destructive current were unsuccessful in that only a few grains of sand were obtained at three stations.

The train of reasoning given above started with the cable breaks. However, if we had no other evidence than the graded layer in the cores we would still conclude that a turbidity current had flowed down the regional slope in very recent time.

DALY, without evidence from cores or evidence from cable breaks, basing his reasoning primarily on the existence of submarine canyons and the evidence for their relatively recent origin, came to the conclusion that turbidity currents are realities. These independent lines of reasoning starting from quite different sorts of evidence but converging to the same conclusion combine to form a convincing argument for the reality of turbidity currents, agents of submarine erosion, transportation, and deposition of sediments.

ACKNOWLEDGMENTS

THE co-operation of the members of the Woods Hole Oceanographic Institution, Captain J. PIKE and the officers and crew of the Atlantis is gratefully acknowledged. D. K. JONES, D. F. ISLES, E. T. MILLER, M. MAJOR and T. R. MADDEN assisted in

obtaining the cores. GOSTA and JANET WOLLIN assisted in the laboratory. MARIE THARP and M. I. WIRSHUP drafted the illustrations.

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(Lamont Geological Observatory Contribution No. 109)

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EDITORIAL NOTE

The following paper has come to the notice of the Editors just prior to this issue of Deep-Sea Research going to press and therefore it has not been called to the authors' attention.

SHEPARD, F. P. (1954), High-velocity turbidity currents : a discussion. *Proc. Roy. Soc.* A. **222** (1150) 323-326.

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Deep-Sea Research, 1954, Vol. 1, pp. 203 to 210. Pergamon Press Ltd., London.

Remarks on the Grand Banks turbidity current

B. KULLENBERG

Summary—The hypothesis is discussed that a turbidity current caused the breaks in the submarine telegraph cables lying down-slope of the epicentral area of the 1929 Grand Banks earthquake. An inspection of the bottom topography makes it appear impracticable for the turbidity current to have approached, from the north, and to have caused several of the cable breaks ascribed to it. Though the hypothesis of a turbidity current is able to account for the fact that the cables were broken in sequence from north to south, it is not able to explain why distant breaks on one and the same cable occurred simultaneously. The direction chosen by the turbidity current indicated by the cable breaks is to the left of the general direction of the slope, whereas it should be slightly to the right of the slope, in view of the action of the deflecting force of the earth's rotation. It is demonstrated that a turbidity current with a limited length should rapidly lose suspension in the rear and become considerably thinner and slower.

INTRODUCTION

IT is suggested by HEEZEN and EWING (1952) that the breaks in the submarine telegraph cables on the continental slope and on the ocean floor to the south of Newfoundland in November, 1929, were caused by a turbidity current initiated by a severe earthquake. The positions and times of several breaks being known, HEEZEN and EWING were able to compute the velocity of the alleged turbidity current. The density and the size of the current were estimated by KUENEN (1952), using the Chézy formula.

OBSTACLES RAISED TO THE TURBIDITY CURRENT BY THE BOTTOM TOPOGRAPHY

The cable breaks which are supposed to be due to a turbidity current are given in Table 1, after DOXSEE (1948) and HEEZEN & EWING (1952).

An inspection of the bottom topography as revealed by the "Carte générale bathymétrique des Océans" (1935), a portion of which is given in Fig. 1, will show that there are topographic obstacles in the path of a turbidity current approaching the Cables J, K, and L from the north. Special interest is centred on the localities where the breaks occurred. A topographical obstacle may consist of a rise sufficiently high enough to obstruct the progress of the turbidity current, or it may consist of a depression which cannot be crossed by the turbidity current unless it is first filled up completely. In view of the high density of the turbidity current (KUENEN 1952) the kinetic energy below Cable 1 is barely sufficient to enable the current to climb a rise 10 m high without diminishing its thickness. By diminishing its thickness the current may climb a higher rise, but not one the height of which exceeds the thickness of the current. We shall review each break of Cables J, K, and L.

Break No. 22. DOXSEE reported a depth of 5,470 m. According to Fig. 1 the depth is about 5,150 m along Cable J 140 km to the east and west of break No. 22. To the north of this portion of the cable there are depths of 5,282 m, 5,371 m, 5,221 m, 5,322 m, and 6,309 m, the last figure indicating an isolated deep immediately to the north of the cable. Judging from this, the turbidity current, before reaching this part of Cable J should pass over a portion of the sea-bed stretching at least 30 km to

the north of the cable, where the sea-bed is sloping northwards. This does not appear to favour the advance of a turbidity current. In view of the great discrepancy between the depth reported by DOXSEE and the " Carte générale bathymétrique des Océans " we shall not, however, attach too great an importance to this break.

Table 1

List of cable breaks attributed to a turbidity current

Break No.	*Lat. N.*	*Long. W.*	*Depth m*	*Time (G.C.T) 11/18/29*	*Interval between quake and break*
H Imperial Cable Company, Halifax–Fayal					
17	43° 37′	55° 15′	3646	2131	0059
18	43° 15′	56° 07′	4011	2131	0059
I French Cable Company, Cape Cod–Brest					
19	42° 05′	55° 30′	4375	2335	0303
20	42° 07′	53° 30′	4740	?	?
21	42° 00′	57° 36′	4557	?	?
J French Cable Company, New York–Fayal					
22	40° 30′	55° 55′	5470	0533	0901
23	40° 28′	52° 06′	5105	0533	0901
K Western Union Cable Company, New York (Hammel) – Bay Roberts (No. 2)					
24	40° 00′	55° 20′	5815	0650	1018
25	40° 02′	54° 50′	5287	0650	1018
26	40° 13′	52° 30′	5105	0850	1218
L Western Union Cable Company, New York – Fayal (Horta) (No. 1)					
27	39° 29′	53° 47′	5068	0949	1317
28	39° 35′	51° 41′	5105	0953	1321

Break No. 23. The depth of 5,105 m reported by DOXSEE is compatible with Fig. 1. To the north and west of the break there are depths exceeding 5,400 m indicating a narrow depression with an eastnortheast direction and a length of at least 90 km. To reach the break, the turbidity current would have to cross the depression and then climb a height of more than 300 m, which it cannot possibly do. The possibility that the turbidity current may force its way by filling the depression needs not to be considered seriously, in view of the fact that the computations of KUENEN (1952) demand such a high density of the current that the suspension would be identical to the bottom deposits in every respect but consistence. Accordingly, the filling up of the depression would be a permanent one.

Break No. 24. If Fig. 1 is correct, it is difficult to see how a turbidity current could reach this break. However, the discrepancy between the sounding reported by DOXSEE and the "Carte générale bathymétrique des Océans" is too great to allow a discussion of the break.

Break No. 25. The depth reported by DOXSEE is compatible with Fig. 1. Immediately to the north of the break there is a basin with a depth exceeding 6,000 m and the break is situated on the southern slope of the basin. The position appears to be extremely well situated to protect this portion of the cable against turbidity currents from the north. A turbidity current cannot reach the break by a frontal approach from the north, as it must then pass the basin, which is obviously impossible. Neither does it appear possible that a turbidity current could reach the break by passing

round the basin, as the current would then be caught by the basin when approaching its margins and rush down the steep slope offered to it.

Break No. 26. This break occurred 2 hours later than the other breaks of Cable K. The depth reported by DOXSEE is compatible with Fig. 1. To the north, west, and south the break is surrounded by greater depths, which should obstruct turbidity

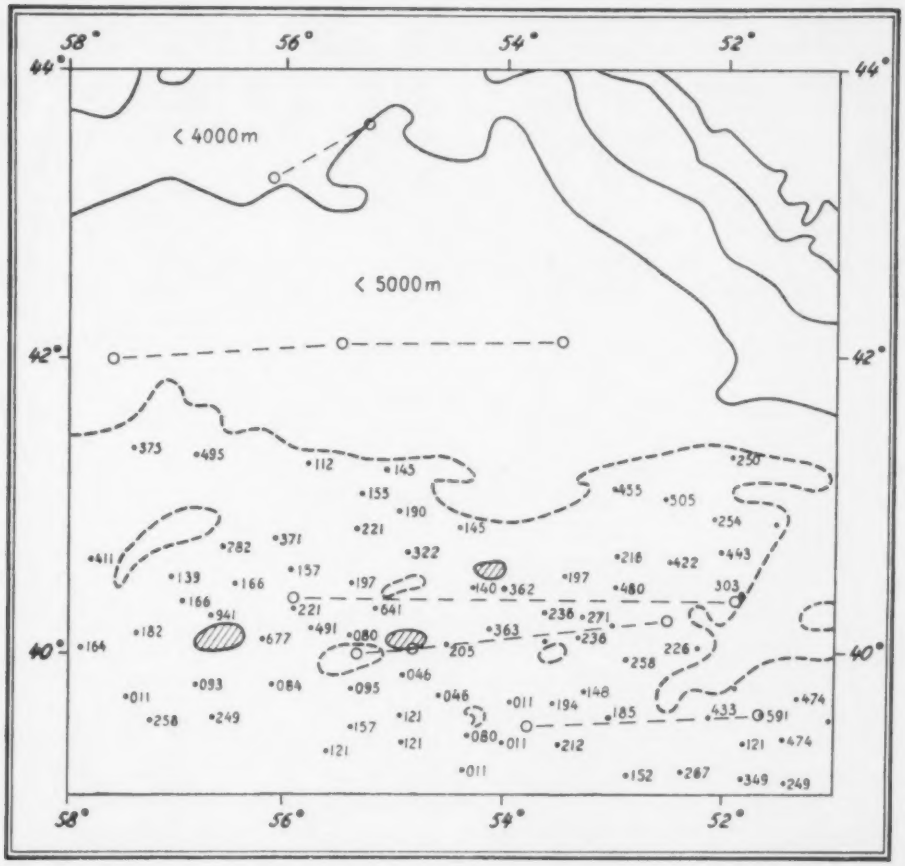


Fig. 1. Positions of cable breaks 17-28 (cf. Table 1). Topography according to " Carte générale bathymétrique des océans," Feuille A 1, 1935. Dashed line indicates the 5,000 m isobath. Hatched area indicates depth exceeding 6,000 m. Soundings between 5,000 and 6,000 m have been written without the first figure (i.e. 375 should read 5 375).

currents approaching from any of these directions. To the east and northeast, on the other hand, there is a rise, the minimum depth of which is 4,372 m, which could not be climbed by a turbidity current advancing on the deeper area to the north of it. It is therefore difficult to see how a turbidity current coming from the northern continental slope could reach this break.

Break No. 27. Locally there seems to be nothing to prevent a turbidity current from reaching this break from the north, *once the current has passed Cable K.*

Break No. 28. A turbidity current cannot reach this break from the north, because

the 5,000-m isobath is pushing far down to the westnorthwest of the break. The elevation indicated by the isobath has a height of several hundred metres above the sea-floor surrounding it to the north and to the south, and it is a most effective barrier to a turbidity current approaching from the northwest. To reach the break the turbidity current must proceed to the west of the 5,000-m isobath and then turn to the left. There appears to be no reason why it should not then cut a point on the cable more westerly than break No. 28, before reaching this break. The distance covered by the turbidity current between Cable K and break No. 28 would, further, be considerably greater than the distance covered to reach break No. 27. As the two breaks occurred almost simultaneously, the current would have obtained a far greater velocity at its left wing than at the right one, or 20 m/sec as compared to 6 m/sec.

On the whole, the preceding discussion of the topography of the ocean floor to the north of Cable J, and between this cable and Cable L, makes it appear improbable that the breaks of the Cables J, K, and L following on the 1929 Grand Banks earthquake were caused by a turbidity current.

THE CONCEPTION OF ISOLATED FAST TURBIDITY CURRENTS AS RESPONSIBLE FOR THE CABLE BREAKS

According to KUENEN (1952) the current will have shown concentration in density and in thickness along depressions on the slope and these fastest lobes will have caused the cable breaks. In this connection we shall draw attention to the remarkable fact that two breaks in each of the cables H, J, K, and L are reported to have occurred almost simultaneously. The first break in a cable is announced by the interruption of the service. It appears that a second break is indicated by a decrease of the resistance of the part of the cable involved, which affords a possibility of ascertaining the time at which the second break occurs. The distances between the breaks here referred to are respectively 80 km, 320 km, 40 km, and 180 km. The last breaks occurred more than 12 hours after the earthquake. It appears to be too much of a coincidence that two, or rather several fast and comparatively narrow currents should keep time with each other over a distance of 450 km, and for more than 12 hours, though the distance between some of them is as much as 200 or 300 km. A velocity difference of 1 knot would be enough to raise the time lag at Cable L from 4 minutes to one hour. The velocity of the fast lobes mentioned by KUENEN being influenced, among other things, by local topographic irregularities – which should be responsible for the very occurrence of these fast lobes – their velocities could not possibly remain equal to within 1% for 12 hours. The theory of individual fast lobes of the turbidity current being responsible for the cable breaks must therefore be rejected.

Even if the front of the turbidity current formed a more or less smooth curve, it is very singular that the current should cut four cables at two distant points simultaneously. In this respect I would refer to the previous discussion of the bottom topography.

THE ACTION OF THE DEFLECTING FORCE OF THE EARTH'S ROTATION

If a turbidity current is fenced in by a suitable topography, as a submarine canyon or valley, the deflecting force of the earth's rotation will make the interface decline to the left, and in other cases the deflecting force will make the current

choose a direction *cum sole* from the direction of the slope. Assuming the turbidity current to have the same direction at all levels above the sea-bed, the angle α between the current and the slope is determined by the equation sine $\alpha = f : \Delta\rho\, g\, S$, f denoting the deflecting force of the earth's rotation per cm^3, $\Delta\rho$ the effective density of the suspension, and S the slope. In view of the limited thickness of the turbidity current and the great distance travelled by it, there can be no great difference between the slope of the interface and that of the sea-bed.

Using the data given by KUENEN (1952 ; Table 1) we find that a turbidity current should have been deviated 7°, 8°, 13°, 11°, and 13° to the right of the slope at Cable H and the intervals between Cables H and I, I and J, J and K, and K and L, respectively. Accordingly, the current should deviate in the mean about 10° to the right of the slope. This is not much, as neither the direction of the slope nor that of the current, is easily determined with accuracy. However, it is noteworthy that the track of the turbidity current, as marked by the cable breaks, rather deviates to the left of the slope. The slope has, on the whole, a north-south direction. The track of the surmised turbidity current deviates about 20° to the left of the main direction of the slope, which is about 30° to the left of the direction which one should expect the turbidity current to choose, considering the action of the deflecting force of the earth's rotation.

THE SIZE OF THE GRAND BANKS TURBIDITY CURRENT

KUENEN (1951) has, by experiment, come to the conclusion that the velocity of a turbidity current is determined by a modified Chézy formula.

$$v = C \sqrt{S} \,.\, \Delta\rho \,.\, m \qquad (1)$$

v denoting the velocity, S the slope, $\Delta\rho$ the effective density of the suspension, i.e. the difference between the density of the suspension and that of the water, and m the hydraulic mean depth which is, approximately, equal to half the thickness of the turbidity current.

The experiments of KUENEN led to a very small value of the Chézy coefficient in the case of turbidity currents, or $C = 125$. However, KUENEN thought he had reason to believe that the coefficient should be greater, and possibly very much so. In trying to judge the size of the Grand Banks turbidity current he has, therefore, chosen $C = 400$, because it appeared necessary to assume a high value, as compared to the one he found experimentally, in order to get a reasonable size of the Grand Banks turbidity current.

However, there are reasons why the Chézy coefficient should be smaller in the case of a turbidity current than in the case of the flow of water in an open channel.

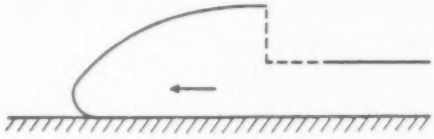
(a) A consideration of the deduction of CHÉZY's formula as given in textbooks of fluid mechanics or hydraulics, will show that KUENEN (1951) has not written down the formula quite correctly. The formula should be written

$$v = C \sqrt{\frac{\Delta\rho}{\rho} \,.\, S \,.\, m} \qquad (2)$$

The presence of the factor ρ in the denominator will make the coefficient C in eq. (1) assume a lower value than in the case of the flow of water in a river. When dealing with density currents with a small effective density we need not consider the factor ρ, but in the case of the Grand Banks turbidity current KUENEN has assumed

the density to be as high as 1·6 and it appears advisable, therefore, not to disregard the factor referred to. In the experiments of KUENEN the neglecting of this factor will have contributed to the lowering of the Chézy coefficient.

However, according to the measurements of KUENEN the velocity of a turbidity current is proportional to the square root of the effective density and does not otherwise depend on the density of the suspension. This does not agree with eq. (2). The discrepancy might be due to the fact that KUENEN has put the slope S in eq. (1) equal to the bed slope. It is not the bed slope, however, that should appear in the formula of CHÉZY but, for open channel flow, the slope of the surface of the current, and the two slopes are not necessarily equal. In the case of a turbidity current the conditions are more complicated than in the case of an open channel flow, because the density is not constant and it is, therefore, in experiments like those carried out by KUENEN, very difficult to measure the effective slope. Further, there is no reason why the effective slope should be the same one in two experiments, with the same bed slope but with different effective density, and this may account for the fact that the experiments did not completely reveal the influence of the density on the velocity of the turbidity current.



(a)

(b)

Fig. 2 (a). Shape of density-current surge front moving with constant velocity (BRAUCHER 1950).
(b). Photo of underflow in a small tank.

(b) There is a difference between the continuous flow of water in a channel and an occasional turbidity current, inasmuch as the water filling a certain portion of the channel has water flowing before it and behind it, whereas the turbidity current has a limited length and has to force its way through water masses which are at rest. The shape of the initial head of an underflow (Fig. 2) has been studied by BRAUCHER (IPPEN and HARLEMAN 1952) who proved that the shape can be presented as a single dimensionless curve, using the maximum thickness as the reference quantity.

KUENEN has taken into account, and rather overrated, the resistance due to the interface shear, by choosing half the thickness of the current as hydraulic mean depth. But there is, also, a resistance raised by the water in front of the initial head of the turbidity current, and this will manifest itself by an increased thickness of the turbidity current in the initial head, as compared to the thickness of a continuous flow.

In this connection we shall discuss, qualitatively, the fact that a turbidity current with a limited length will continuously lose suspension in the rear. A density current which is maintained by a continuous flow will be able to advance at a constant velocity, and behind the initial head it will be able to have a constant thickness. If the current is not maintained by a continuous flow, but has a limited length, the thickness must begin to decrease at some distance behind the initial head, and here the *tail* of the current commences. In the main current behind the initial head the slope of the interface may be equal to that of the sea-bed, but in the tail the slope of the interface is necessarily smaller than that of the sea-bed. If the difference between the two slopes is insignificant, this imports that the current has a very great length, and that much larger quantities of sediment are involved than has been assumed by KUENEN. At Cable H the tail will be about 90 km long, if the slope of the interface is half of the slope of the sea-bed, which is 1 : 170, and we adopt the thickness of the current given by KUENEN, which is 270 m. Owing to the smaller slope of the interface, the velocity of the tail will be considerably smaller than that of the initial head of the current, or 30% smaller in the fore part of the tail. As a consequence the thickness of the tail will decrease, the slope of the interface will diminish in the transition between the main current and the tail, and the transition will advance into the main body of the current. At the high velocities here encountered this will happen quickly, and the tail will very soon reach the initial head of the current. As soon as the thickness of the current behind the initial head begins to diminish, the maximum thickness of the head will diminish as well, because there is a constant ratio between the maximum thickness of the head and the thickness of the current behind it (IPPEN and HARLEMAN 1952). As a consequence the velocity of the turbidity current will decrease. It may be concluded that a turbidity current that is not maintained by a continuous flow, or is able to support itself by erosion, will quickly be dispersed over a great area in the direction of the current, and lose thickness and velocity.

THE DECREASE OF THE DENSITY OF THE SUSPENSION WITH THE HEIGHT ABOVE THE SEA-BED

The density distribution in a turbidity current has been computed by MENARD and LUDWICK (1951) in an arbitrary example. The density was found to decrease very rapidly with the height, the effective density being reduced by a factor of the magnitude $\frac{1}{10}$ from a 2 m thick layer near the bottom to a level 25 m higher. If a similar computation could be effected under the conditions prevailing in the Grand Banks turbidity current, it should be possible to state the maximal mean effective density of the suspension as a function of the thickness of the current, the maximal density of the near-bottom layer being given as the density of the deposits. The importance is evident : KUENEN has found it necessary to reckon with a thickness of 270 m and a mean density of 1·6 of the turbidity current near Cable H, and a computation of the density distribution should tell us whether a turbidity current of such a thickness could possibly obtain such a high mean density.

However, for the present we shall refrain from attacking the problem from this quarter in view of the difficulty of judging at the exchange coefficient, which must obviously be very high in view of the extremely high velocities, and the necessity to preserve a suspension with an extremely high concentration. Further, the settling velocity of coarse matter is diminished by clay in suspension, which would also affect the vertical density distribution. Both facts would tend to diminish the variability of the density with the height, which favours the maintenance of the calculations laid down by KUENEN (1952). On the other hand, a reduced variation of the density with the height above the sea-bed would deprive the turbidity current of one essential feature, i.e. the faculty to bring about graded beddings.

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On the age-determination in deep-sea sediments by radium measurements

VIKTOR S. KRÖLL

Summary—The possibility of dating deep-sea sediments by radioactive measurements is discussed. The vertical distribution of radium is mainly influenced by three factors, namely (1) the rate of accumulation of ionium, (2) the total rate of deposition, and (3) the diffusion and adsorption of radium or ionium. Hence a knowledge of the geochemistry of the radioactive elements is necessary to obtain the dating.

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RADIOACTIVE age-determinations in sediments cannot be carried out with the methods used for the igneous rocks, since the content of uranium, lead and helium depends on the age of the minerals deposited, and the clay formation destroys the relationship. One of the radioactive elements has to be enriched in the sediment to allow the use of radioactive methods. Ionium or radium should be convenient for younger deep-sea sediments. Because of the lack of thorium in seawater and the high radium content in the surface layer of deep-sea sediments, H. PETTERSSON (1937) pointed out that ionium is supposed to be precipitated from sea-water and the accumulated ionium decays in the sediment.

PIGGOT and URRY (1941) introduced radium determinations as a means of dating sediment cores, or computing the rate of sedimentation. They concluded from the distribution of radium and uranium (URRY, 1941) that the radioactive elements form a " non-equilibrium system " in the sediment. For this system URRY (1942) has given the general equations from which the surface value of radium, ionium and uranium could be ascertained. In this way one gets the theoretical trend of the radium concentration with the time for the special conditions in the core under consideration. URRY attains a T-cm dating relationship by comparing the ordinates of the experimental curve with the theoretical. But this method is not applicable to curves which show more than one maximum in the radium concentration, as for example, about two-thirds of those published by PIGGOT and URRY.

It should be stressed that, by explaining the radium distribution by radioactive decay and variations in the rate of sedimentation, PIGGOT and URRY (1942) had to postulate that the ionium concentration in the matter settling on the ocean floor is independent of time.

Seventeen cores (13 from the Pacific and 4 from the Atlantic Ocean) of the Swedish Deep-Sea Expedition have been measured by the writer for radium. In some of the cores ionium has been determined by PICCIOTTO and uranium by HECHT. Generally the radium-distribution is very different from the prototype given by PIGGOT and URRY. There is no smooth curve, showing the theoretical trend for radium-growing and ionium-decay, but two or more maxima and minima. To explain this it is necessary to abandon the suppositions made by PIGGOT and URRY.

The measurements of radium, ionium and uranium prove that radium occurs mainly ionium-supported. The uranium-supported radium in the upper strata of the

sediment constitutes only a few per cent. In view of the rise of the radium-concentration immediately below the sediment surface generally encountered, the unsupported radium may be considered as negligible.

We shall consider what other circumstances influence the distribution of radium in the sediment. Then we will first dismiss the assumption by PIGGOT and URRY that the ionium concentration does not vary with time in newly-deposited sediment if the general composition does not vary. This assumption is not compatible with the observations and especially not with the existence of a second maximum as the radium disintegration curve may approach the horizontal line with increasing rate of deposition, but cannot rise a second time. An attempt to explain the vertical variation of the radium concentration by a change in the character of the sediment, would exclude the possibility of radioactive dating, because a change of the rate of deposition is almost always connected with a change of the composition of the sediment.

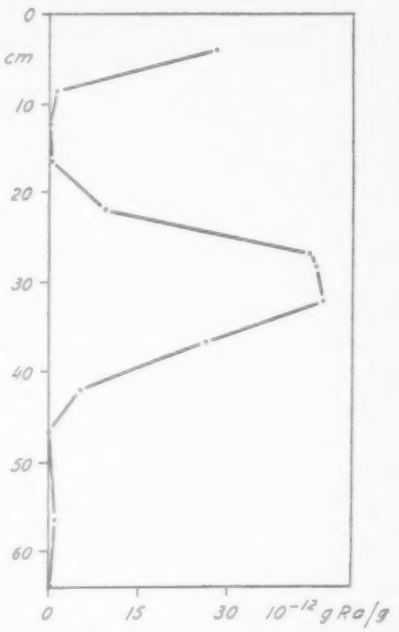

Fig. 1. Distribution of the radium concentration in Core 83, station 130, 169° 28'W 08° 04'N, depth 5440 m.

We shall discuss another possibility that might be maintained in defence of the hypothesis of PIGGOT and URRY : it might be suggested that the initial ionium concentration is constant as a consequence of adsorption to the particles, but is changed later because a part of the sediment is brought into solution. In this case the method of dating used by PIGGOT and URRY would give neither a correct dating nor a correct rate of deposition.

There is another reason why a constancy of the initial ionium concentration is unlikely. As we shall prove later the ionium concentration in the sediment surface has the magnitude to be expected if the ionium originates from the uranium dissolved in the sea-water. The initial ionium concentration should therefore, approximately, be reciprocably proportional to the rate of deposition (unless the rate of deposition is, exceptionally, too small to allow all the ionium present in the water to be carried to the sea-floor, which may, perhaps never be the case).

Since, moreover, the uranium concentration of the seawater is practically constant in the ocean (KARLIK and HERNEGGER, 1935 ; G. KOCZY, 1950) a complete mixing is supposed to occur in 100-1,000 years, so the formation of ionium does not depend on the local rate of deposition. We shall, therefore, not discuss the deposition of ionium in terms of the ionium concentration of the sediment but shall use the conception rate of accumulation of ionium.

The distribution of radium in the sediment is mainly influenced by

(1) the changes of the rate of accumulation of ionium,
(2) the changes of the total rate deposition, and
(3) the diffusion and adsorption of radium or ionium in the sediment.

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I. THE CHANGES IN THE RATE OF ACCUMULATION OF IONIUM

Though the process of the deposition of ionium is not yet known, it appears necessary to assume that the rate of accumulation of ionium has changed during the time here considered.

The accumulation of ionium is dependent on the uranium concentration of the sea-water or, at any rate, on the amount of ionium present in the sea. In integrating the amount of ionium-supported radium in vertical sediment-columns, I have found a higher value in several cores than corresponds to the present uranium contents in the water-column above the core. The amount of ionium-supported radium corresponding to the uranium in the sea-water was computed under the supposition of a mean uranium-concentration of $1{\cdot}3 \cdot 10^{-6}$ g/U per Io, and a complete deposition of all ionium produced by the uranium in a water-column with the mean depth of the ocean.

If the ionium-concentration in the sediment surface is computed from the radium-concentration upon the assumption of a constant total rate of deposition between the top of the core and the level L_0 defined below, we arrive at a present rate of accumulation of ionium equal to the supply of ionium due to decay of the uranium in the sea-water. The assumptions on which the computations have been founded may be open to dispute. If they are correct, it follows that the uranium content in the sea-water is not a constant in time and that no unsupported ionium is carried to the sea at present. That the supply of uranium to the sea and the uranium content of the sea-water (life-conditions for the uranium-precipitating bacteria, etc.) varies with the climate is easy to see, especially as F. KOCZY (1953) has recently found a supply of uranium that should double the uranium content of the sea in about 60,000 years. Measurements by LAHNER (1939) and KROPF (1939) indicate that, through the weathering of limestones and dolomite, uranium is brought in to solution more effectively than radium and, even more so, than thorium and probably than ionium. This is probably also the case through the weathering of other kinds of rock.

But if it can be proved, by direct measurements of the ionium concentration, that the initial concentration of ionium corresponding to the integrated amount of radium is higher than that to be expected from the uranium concentration in sea-water, there must be a diffusion of radium from the sediments to the sea and, further, a supply of unsupported ionium to the sea.

Apart from the temporary changes of the ionium content of the sea, changes in the process of deposition of ionium appear to be highly probable whether the ionium is brought to deposition by precipitation, adsorption or through biological extraction.

Provided that the rate of deposition is constant, the changes of the rate of accumulation of ionium can be determined in the following way. Assuming a constant rate of accumulation of ionium, we compute the theoretical radium disintegration curve which will give the measured amount of ionium-supported radium in the sediment column down to the level L_0 where the radium-concentration is equivalent to the uranium-concentration within the limit of error, and at which level the radium disintegration curve will show the observed radium-concentration (KRÖLL, 1953) If we then compare the observed radium-concentration at a certain depth or time T with the radium content at the same depth, as given by the radium disintegration curve, the quotient of them will give the quotient of the rate of accumulation of ionium at the time T and the mean rate of accumulation of ionium down to level L_0. It

should then be possible to make conclusions concerning the changes in the supply of uranium (weathering, climate, etc.), or the chemical conditions in the sea as caused for instance by submarine eruptions or by the power of adsorption displayed by the sediment.

2. THE CHANGES OF THE TOTAL RATE OF DEPOSITION

If the rate of accumulation of ionium is supposed to be constant, and the variation of the radium-concentration in the sediment is due to changes in the rate of deposition, these variations can be determined in the following way. A theoretical radium disintegration curve is determined as indicated in the preceding paragraph. By integrating the disintegration curve we find the total amount of radium present in the sediment column down to a level corresponding to the time T, as a function of T. By integrating the measured radium-concentration (after having subtracted the uranium-supported radium) we find the total amount of ionium-supported radium in the sediment column down to a level x, as a function of x. A comparison of the two integrations will give the date of any level in the core down to L_0. In the cores investigated by me, this method has led to very considerable variations in the rate of deposition, which may be due to horizontal transportation caused by submarine eruptions. Thus we arrive at a high rate of deposition during the most recent period (it should be pointed out, however, that the possible existence of unsupported radium near the top of the core will cause some uncertainty here) and a brief period with a very high rate of deposition about 100,000 years ago. This would indicate intense volcancity in the central Pacific during the last mentioned period. It appears probable that intense volcanic activity should lead to transporation of sediment over long distances by convection currents due to the heat developed at the loci of the eruptions.

3. THE DIFFUSION AND ADSORPTION OF RADIUM OR IONIUM

It is necessary to take into account the possibility of diffusion of ionium or radium in the interpretation of the vertical distribution of radium in the sediment. Though minerals are formed in the sediment, which must be connected with diffusion of certain ions, the observations indicate that there is no important diffusion of radium or ionium. More direct determinations of the ionium-concentration will give information about the diffusion of radium.

The method of determining a mean rate of deposition (KRÖLL, 1953) is applicable even in the case of a diffusion of radium, provided that, at the level L_0, not only is the diffusion small but also the total rate of deposition and the rate of accumulation of ionium at the same level do not differ appreciably from their mean values.

A few values of the mean rate of deposition computed according to the method referred to are shown in Table 1. Certain difficulties excluded the use of this method in the case of the cores 76B and 98B. The rate of deposition in these cores was determined, approximately, by the uppermost radium maximum upon the assumption that this maximum is equivalent to the initial ionium-concentration, and that the rate of accumulation of ionium corresponds to the uranium content to the sea (PETTERSSON, 1951).

We may conclude that it is necessary to take into consideration mineralogical chemical, topographical, and other conditions when trying to date deep-sea deposists by means of radioactive measurements. This problem is not merely a problem of

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radioactivity, but mainly a question of the geochemistry of the radioactive elements – uranium, ionium and radium.

A detailed paper will appear in the *Reports of the Swedish Deep-Sea Expedition.*

Table 1

The average rate of sedimentation during the last 3-400,000 *years*

Core-number	*Position*	*Average rate of sedimentation in mm/1,000 years*
69 B	149° 30′W 13° 25′S	1·3
76 B	149° 44′W 03° 45′N	(*) 3-4 (part with red clay) resp. (*) 15-20 (calcareous part of sed.)
83 B	169° 28′W 08°40′N	1-2
83	169° 28′W 08° 40′N	1·2-1·5
85 B	172° 12′W 05° 34′N	1·7
86 B	172° 19′W 04° 02′N	1·2
87 B	173° 50′W 02° 23′N	1·2-1·3
87	173° 50′W 02° 23′N	2
98 B	152° 37′E 01° 40′N	(*) 20
101	145° 47′E 02° 11′N	6-7
238	18° 12′W 00° 07′S	20
281	44° 20′W 34° 54′N	7-10

The error is about 20%.

(*) Values found by comparing the Io-supply from the sea-water with the Io-surface value (vide text)

ACKNOWLEDGMENT

I wish to thank Professor H. PETTERSSON for making it possible to carry out these investigations in his Institute and for his valuable advice.

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Distribution and abundance of the diatom *Ethmodiscus rex* off the west coast of North America*

J. L. McHugh†

Summary—*Ethmodiscus rex*, though not present in great numbers, is a common constituent of the plankton throughout the year off the California and Lower California coasts. It has been collected in plankton hauls from 46° 15′ to 23° 45′ N. Lat., and from within a few yards of shore to 400 miles off the coast. The cells are rather variable in size and shape, and reach a maximum diameter of almost 2 mm. The species appears to be most abundant in the offshore waters. Its occurrence as an important constituent of deep-sea deposits in the western Pacific Ocean may be a consequence of its widespread distribution in the plankton.

INTRODUCTION

Recent studies of deep-sea bottom deposits in the tropical Pacific Ocean (Hanzawa, 1933 ; Wiseman and Hendey, 1953) have shown that skeletons and fragments of *Ethmodiscus rex* (Rattray) Hendey often are the dominant constituent. Wiseman and Hendey (1953) were at a loss to account for this phenomenon, stating that the species has been found very seldom in the living state in plankton samples, and concluding that the vegetative season may be short, and that the species probably multiplies suddenly in enormous numbers. A bottom sample taken at 11° 20′N. Lat., 142° 19′E. Long., five miles from the greatest known oceanic depth, was dominated by *E. rex*, yet the diatom was not found in the plankton in this region.

Cupp (1943) did not list *Ethmodiscus rex* from the waters off the west coast of North America, although she and others examined many thousands of samples. Recent studies, however, have shown that the species is not uncommon in the waters off California and Lower California. The first record of *E. rex* in these waters was at Melpomene Cove, Guadalupe Island, in December 1946, when a single cell was taken in a vertical haul with a small plankton net. During Cruise 50 of the *E. W. Scripps*, 30 stations were occupied off the coast of Lower California (Fig. 1). At each, an oblique haul was made with a plankton net one metre in diameter at the mouth, constructed of cottom scrim with mesh openings of 0·80 to 0·95 mm. (Ahlstrom, 1948). The duration of each haul was approximately 20 minutes, during which the net moved forward and upward from a depth of approximately 70 metres to the surface. Of these 30 samples, 15 contained one or more specimens of *E. rex*. The volume of water filtered during each haul, usually about 500 cubic metres or more, was measured with a current meter suspended in the mouth of the net, and the hauls were standardized in terms of the numbers of organisms under 10 square metres of sea surface. On this cruise, the greatest number of cells of *E. rex* per standard haul (74 cells) was at station 5 (29° 38′N. Lat., 119° 19′W. Long.).

When the cruises of the California Co-operative Sardine Research Programme (now the California Co-operative Oceanic Fisheries Investigations) began in 1949, plankton hauls similar to those described above were made at each station. The

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† Formerly with Scripps Institution of Oceanography.

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methods by which the hauls were made are described in more detail by AHLSTROM (1948, 1952). The first operation in examining the samples was to remove all fish eggs and larvae from the entire sample, or from a large aliquot part. Through the courtesy of DR. ELBERT H. AHLSTROM, in charge of this phase of the programme, the technicians were instructed to record the occurrence of *Ethmodiscus* as they sorted the samples. No checks were made on the accuracy of these counts, but because the species is distinctive in size and shape it is unlikely that errors of identity were made. It is considered likely, however, that the various technicians varied in

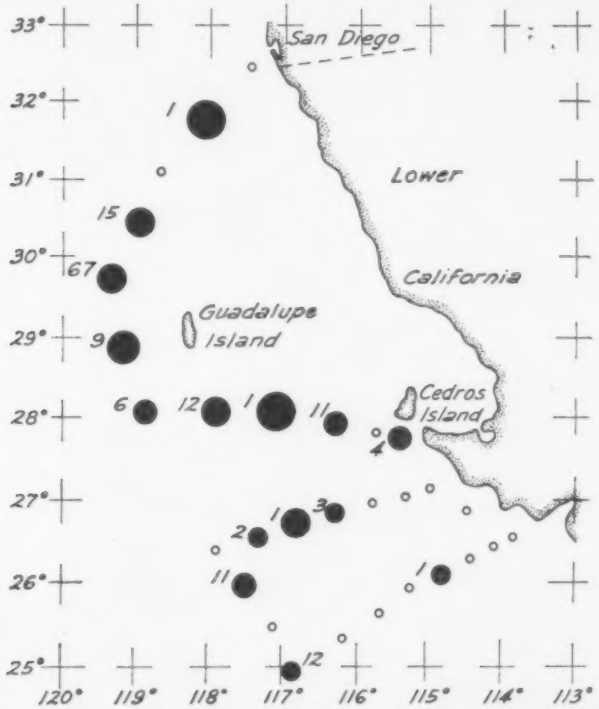

Fig. 1. Station pattern of Cruise 50 of the *E. W. Scripps*, February 1948, showing the numbers of *Ethmodiscus rex* and the relative average size of the cells taken at each station. The diameters of the black circles are proportional to the average valve diameters of the cells ; the number of cells is indicated opposite each circle ; the small open circles are stations at which no *Ethmodiscus* were found.

their interest, and in their ability to see the diatom when their attention was concentrated on the eggs and larvae of fishes. For this reason, these counts are not listed here, although they have been used as the basis for general remarks on geographic and seasonal distribution. The distribution pattern of *E. rex* during Cruise 50 of the *E. W. Scripps*, based on counts made by the author, is so similar to the distributions deduced for these other cruises, however, that considerable confidence can be placed in the relative reliability of these data.

GEOGRAPHIC DISTRIBUTION

The known geographic range of *Ethmodiscus rex* off the west coast of North America extends from the Washington coast to the coast of Lower California (46° 15'N. Lat.

23° 45′N. Lat.). This coincides with the region covered by the cruises from which *Ethmodiscus* counts are available, namely, Cruises 22 and 50 of the *E. W. Scripps* and Cruises 1 to 7 and 11 to 14 inclusive, of the California Co-operative Sardine Research Programme. Undoubtedly, when the areas to the north and south are investigated, it will be shown that the present known limits (Fig. 2) do not represent

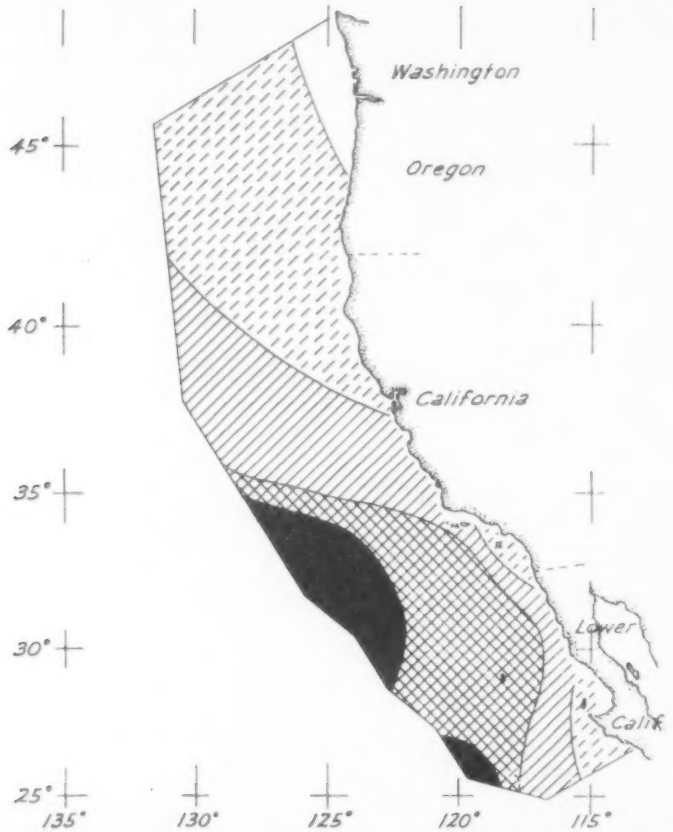

Fig. 2. Relative density of *Ethmodiscus rex* off the west coast of North America as observed on Cruise 50 of the *E. W. Scripps* and Cruises 1 to 7 and 11 to 14 inclusive of the California Co-operative Sardine Research Programme. The density of diatoms is proportional to the density of shading. Absolute values are not indicated because the true magnitude of such values is lost in the averaging process. The original standardized counts, however, ranged from zero (most frequent in the inshore zone to the north) to more than 100 (most common in the offshore zone to the south).

the extreme limits of the species range. For example, *Ethmodiscus zodiacus* has been reported from the coastal waters of British Columbia (BAILEY and MCKAY, 1916), and it is possible that this record was based on *E. rex*. In an east-west direction also, the known distribution of *E. rex* in the plankton coincides with the bounds of the survey area. Thus the species has been taken at stations from within a few yards of shore to 400 nautical miles seaward.

The orginal data, too unwieldy to present in detail, are summarized in Tables I and II. To reduce the number of observations to convenient form, the area was divided

into 21 blocks, 3 blocks east to west, and 7 north to south, by lines running roughly parallel and at right angles to the coast. These blocks were numbered 1 to 7 from north to south, and *A* to *C* from east to west. All available observations made within each block were averaged. These averages demonstrate numerically, as Fig. 2 illustrates graphically, that *Ethmodiscus* was more abundant offshore, and toward

Table I. Relative abundance of Ethmodiscus rex from north to south, expressed as the percentage of standard hauls in each area containing 20 cells or more.

Block number	*Approximate latitude of centre of area*	*Percentage of hauls containing 20 cells or more*	*Number of hauls*
1A-1C	45° 00′N	0	59
2A-2C	41° 30′N	1	98
3A-3C	38° 00′N	9	200
4A-4C	34° 30′N	21	173
5A-5C	31° 00′N	19	272
6A-6C	28° 00′N	18	230
7A-7C	24° 30′N	8	97

Table II. Relative abundance of Ethmodiscus rex from east to west, expressed as the percentage of standard hauls in each area containing 20 cells or more.

Block number	*Approximate distance in miles from shore to centre of area*	*Percentage of hauls containing 20 cells or more*	*Number of hauls*
1A-7A	40	3	174
1B-7B	125	16	563
1C-7C	300	18	392

the south, in the area from Point Conception south to the vicinity of Guadalupe Island, and westward to the offshore boundary of the survey area. Off the Washington coast the species occurred only occasionally, and many hauls contained no cells ; off central Lower California it was less abundant than immediately to the northward, but still was present in most hauls, and occasionally was fairly abundant.

In an east-west direction abundance was least near the coast, and the frequency of occurrence increased steadily with distance offshore. It would appear that this is a typically oceanic species.

SEASONAL DISTRIBUTION

There is no evidence that the abundance or the pattern of distribution of *E. rex* varies regularly with the seasons in the area studied. Data are available for all months of the year except October and November, and charts showing the distribution for each of the 12 cruises are remarkably similar in their general features. It seems likely that when the distribution in October and November is known it will prove to be similar to the average pattern for the ten months covered by the surveys (Fig. 2).

ABUNDANCE

Records of the number of individuals of *Ethmodiscus rex* under 10 square metres of sea surface are available for 1,129 plankton hauls. Of these, 402 contained no cells,

and 727 contained numbers ranging from 1 to 176. Most of the blank hauls occurred off the Washington and Oregon coasts, and it was unusual in any month to find no cells off California and Lower California except in the waters near the coast of Lower California, south of Cedros Island. Since the hauls were made primarily to collect fish eggs and larvae, they seldom exceeded 70 metres in depth. It is possible that, especially in clear oceanic water, the nets did not reach the lower limit of the photosynthetic zone, and thus the hauls were not strictly representative of the entire population. Errors would be introduced also by failure of the net to retain the smaller cells.

VARIATIONS IN SIZE AND SHAPE

Ethmodiscus rex and some of its close relatives are the largest diatoms known. Hendey (Wiseman and Hendey, 1953), in the only satisfactory description of *E. rex* available, states that the valve diameter ranges from 1·7 to 1·9 mm.

Measurements of 156 specimens from *E. W. Scripps* Cruise 50 show that in waters off the Lower California coast the size is much more variable. In this material the valve diameter ranged from 0·34 to 1·81 mm, the pervalvar axis from 0·32 to 1·36 mm, and the girdle width from 0·21 to 1·13 mm. The size of the smallest cells may have been determined by the mesh size of the net. The shape of the valves showed extreme

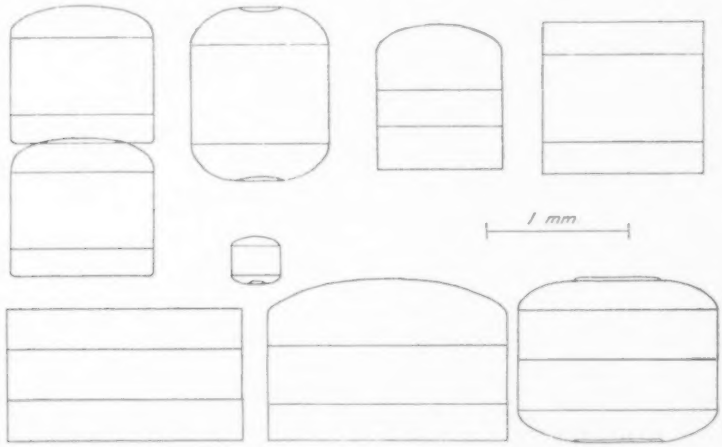

Fig. 3. Selected specimens of *Ethmodiscus rex* from *E. W. Scripps* Cruise 50, shown in girdle view to illustrate the wide variation in size and shape.

variation also, from relatively long cells with convex valve mantles, to squat pillbox-like structures with one or both valve mantles flat. Some of the many variations in size and shape are illustrated in girdle view in Fig. 3. A slight concavity often is present in the centre of the valve. This apparently represents the surface of attachment of recently-divided cells, a pair of which is shown at the upper left in the figure.

As indicated in Fig. 1, the average valve diameter in these samples tended to decrease from north to south. This decrease is illustrated in more striking fashion by the average diameters of all cells taken at stations 1 to 5 (140 mm), 6-12 (120 mm), and 13-30 (95 mm). Such size changes are characteristic of diatoms in the cycle from auxospore formation through successive cell divisions.

DISCUSSION

Although *Ethmodiscus rex* has not been reported previously as a constituent of the plankton in the temperate and tropical Pacific Ocean, it has been found in large numbers in bottom deposits. The importance of these deposits has been described vividly by MANN (1907), who stated that in a belt over 3,000 miles long from east to west, and perhaps 20 miles wide, between the islands of Guam and Luzon, the bottom deposits are composed chiefly, and often exclusively, of the remains of *Coscinodiscus rex*. The distance stated is in error, for it is roughly only about 1,500 miles from Guam to Luzon, but this is of minor importance.

Since phytoplankton organisms usually are present in tremendous numbers in relatively small volumes of water, it is customary to filter only small quantities, usually not more than a few litres, to obtain a satisfactory quantitative sample. Thus, species such as *Ethmodiscus rex*, with wide and relatively uniform oceanographic and seasonal ranges, but otherwise scarce, will be missed by conventional methods. A possible factor responsible for this relative scarcity may be the large size of the cells, limiting the diffusion of nutrient materials into the cell, thus limiting the rate of cell division.

It is not necessary, therefore, to postulate a short vegetative season to account for the rarity of *Ethmodiscus rex* in phytoplankton samples. The present data, indeed, seem to suggest that the vegetative season is continuous. There is no evidence that dense blooms of this species occur within the area surveyed, but this is not strange, for *E. rex* was found for the most part in the region of the California Current, beyond the effect of coastal areas of upwelling. The California Current is a wide body of water that moves sluggishly (SVERDRUP, JOHNSON, and FLEMING, 1942) and conditions conducive to the production of phytoplankton blooms would not usually be expected there. SVERDRUP and ALLEN (1939) showed that offshore water contains few diatoms, while inshore water may contain large numbers, off the southern California coast. They emphasized also that the " age " of the water was important. In the region of the equatorial currents, however, the circulation is such that the supply of nutrients in the photosynthetic zone is constantly being renewed. GRAHAM (1941) and KING and DEMOND (1953) have shown that in the open Pacific plankton is most abundant near the equator, where upwelling associated with the equatorial currents is a prominent phenomenon. This feature of the oceanic circulation may be associated with the occurrence of *Ethmodiscus* deposits in the western Pacific. The widespread distribution of this species in the area surveyed, if it is indicative of a similar distribution across the entire Pacific Ocean, would favour the occurrence of blooms, since presumably at least a few cells would be available whenever and wherever conditions favourable for rapid multiplication arose.

It is well to note, however, that RIEDEL (1954) indicates the possibility that the great bottom deposits of *Ethmodiscus* may be fossil. This certainly would seem to be the origin of the layer of *Ethmodiscus rex* found 793 cm below the bottom in a core from the Atlantic Ocean (WISEMAN and HENDEY, 1953).

The wide variation in cell size in the region covered by Cruise 50 of the *E. W. Scripps* raises a question concerning the homogeneity of the material. These samples were sorted and the measurements made by the author, and, although all the cells were not subjected to detailed taxonomic scrutiny, no obvious differences in sculpture were observed that might suggest the existence of more than one species. WIMPENNY

(1936, 1946) has indicated a range in cell diameter of from 20 to 120 microns for *Rhizosolenia styliformis* in the North Sea, but has concluded that two distinct varieties were represented. LUCAS and STUBBINGS (1948) have stated that *Biddulphia sinensis* in the same region varies in size from 46 to 278 microns, and have noted that the size distribution of *Rhizosolenia* and *Biddulphia* over the region is related to the pattern of water circulation. GARSTANG (1937) also has commented on the value of *Rhizosolenia styliformis* as an indicator of water movements.

Although the available measurements of *Ethmodiscus rex* are too few to permit definite conclusions, they suggest several interesting possibilities. The regular decrease in average size from north to south is consistent with the pattern of oceanic circulation off the coasts of California and Lower California, for the California Current flows in a southeasterly direction, and successive cell divisions would lead, therefore, to a southward decrease in size. Further study may show that *Ethmodiscus rex* is a valuable indicator of the movement of surface waters in the Pacific Ocean.

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AUTHOR'S NOTE

While this paper was in press, it was suggested by Dr. WISEMAN after conversation with Dr. HENDEY, that perhaps the diatom in question was some species of *Ethmodiscus* other than *E. rex*. Drawings made in 1948 by the author and Dr. BRIAN P. BODEN were not sufficient to settle this point, and formalin-preserved specimens from Cruise 50 of the *E. W. Scripps* were so badly fragmented that reconstruction of the cells seemed practically impossible. Through the courtesy of Dr. BODEN, and DAVID KRAMER of the U.S. Fish and Wildlife Service, a single specimen was obtained, 1·5 mm in valve diameter, taken in a plankton net at station 130.40 (26° 09′N. Lat., 114° 08′W. Long.) on October 12, 1953. In the opinion of the author, after careful examination, this specimen unquestionably is identical with *E. rex* as described by WISEMAN and HENDEY (1953), on the basis of the following characteristics :

The valve margin has a narrow hyaline band. The valve surface bears radiating lines of puncta, 3 in 10 μ. Toward the valve margin and on the valve mantle these puncta are somewhat closer together, averaging about 4 in 10 μ. Toward the centre of the valve the lines of puncta give way to an irregular arrangement in which the characteristic tubular holes or pores described by WISEMAN and HENDEY appear. These pores are scattered more or less at random throughout the central area. The puncta on the girdle are slightly closer together than those on the valve, about 5 in 10 μ, and there are narrow hyaline bands on the margins of the girdle. At the ends of the girdle the lines of puncta appear to be flared out at the lower corners.

Dr. BODEN, in a recent letter, states that he is convinced that this material from the plankton is *E. rex*. He points out also that Dr. PAUL S. CONGER, of the U.S. National Museum, several years ago compared samples of our material with specimens in the Museum collection, and reached the same conclusion. Although the taxonomic status of the various diatoms assigned to the genus *Ethmodiscus* needs to be clarified, there is no evidence that the material described here differs from that examined by WISEMAN and HENDEY.

Deep-Sea Research, 1954, Vol. 1, pp. 224 to 248. Pergamon Press Ltd., London.

Sorption reactions and some ecological implications*,†

DAYTON E. CARRITT and SOL GOODGAL§

Summary—The sorption of dissolved substances on suspended solids in natural waters has been examined using, (1) field data taken in the lower Chesapeake Bay, and (2) the results of radio-tracer studies carried out in the laboratory.

The field data, which were measurements of turbidity, total phosphorus, and dissolved inorganic phosphorus, have been tested for a fit to the Freundlick adsorption isotherm in an attempt to demonstrate an adsorption reaction between the dissolved phosphate and the suspended solids. The result is inconclusive. The simplifications required in such a treatment are discussed.

The laboratory data include the results of measurements of the uptake of phosphate, iodide, iron (III), strontium, sulphate and copper (II) by samples of Bay sediments, commercial bentonite, Fullers Earth, and powdered pyrex glass under controlled conditions of temperature, salinity, pH, and contact time. A mechanism for the uptake of phosphate composed of a rapid adsorption process and a much slower diffusion controlled reaction is proposed. The stability of the sorption complexes was measured.

The environmental characteristics of estuaries and the measured sorption properties suggest a mechanism by which dissolved substances can be removed by sorption processes from turbid fresh waters, transported to and then released in estuarine regions where fresh and sea water mix.

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INTRODUCTION

The sorptive properties of solid particles suspended in natural waters have been frequently mentioned but seldom measured. RUTTNER (1953) noted that a large number of these substances may function as adsorbents – he gave clay particles the dominant role, and mentioned (p. 187) " gels of ferric hydroxide and silicic acid, humus colloids, the polymorphic inorganic and organic complexes, and finally the surfaces and integuments of living and dead organisms. Separation of the effects of these various adsorbents in sediments is in general scarcely possible." The same author quoting studies by OHLE noted that adsorption processes carried on by colloidal gels act to regulate the concentration of dissolved nutrients in lakes.

HUTCHINSON (1941) described the phosphorous cycle in Linsley Pond, Connecticut as a closed cycle in which sedimentation by phosphorus rich particulate matter and regeneration from the bottom muds played an important role.

COFFIN *et al.* (1949), and HAYES and COFFIN (1951) added radioactive phosphorus to lakes and followed the dispersion of the radioactivity. Several factors appeared to contribute to the disappearance of phosphorus from solution. The photosynthetic activity of phytoplankton removed a part of it. In one case radio phosphorus was detectable in the phytoplankton but not in the water from which they were taken. Precipitation of ferric phosphate may have removed another part, as postulated by HAYES and COFFIN. Sorption onto suspended solids may have removed still another

* Contribution No. 18 from the Chesapeake Bay Institute.

† The results of work carried out for the Office of Naval Research of the Navy Department ; the State of Maryland (Department of Research aud Education) ; the Commonwealth of Virgina (Virginia Fisheries Laboratory); and the United States Atomtic Energy Commission, under contract with The Johns Hopkins University.

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part. In addition, the local concentration of total phosphorus must have been continually reduced by diffusion and eddy mixing. It is difficult, if not impossible, using the published data, to determine the relative importance of each of these processes to the phosphorous cycle. Since the relative contribution of each of these processes to phosphorus turn-over will depend to a large extent on local conditions, the calculated two weeks turn-over period would appear to apply only to the situation tested.

ALLEE *et al.* (1950) discuss the ecological implications of adsorption processes. They noted, however, that " Adsorption has been little studied from the ecological point of view ; - - " Their discussion of the processes in natural systems is based on analogy with the much simpler colloidal systems that have been studied in the laboratory.

KELLEY writing in Trask (1939) described some of the base exchange properties of marine sediments. He showed that some of the clay mineral components of sediments have relatively high base exchange capacities, but noted only experiments in which cation exchange was studied. He concluded that marine clays will contain as much replaceable magnesium as sodium, despite the ten-to-one ratio of sodium to magnesium in sea water.

REVELLE, quoted in SVERDRUP *et al.* (1942), measured the base exchange capacity of three clay samples collected in the Pacific Ocean during the seventh cruise of the Carnegie and found the capacity to be relatively high and to increase with decreasing particle size.

SVERDRUP *et al.* (1942) summarized the marine aspects of base exchange by clays and noted that " The question of whether or not any exchange takes place when terrigenous clays come in contact with sea water is unsettled."

WEISS (1951) demonstrated a sorption reaction between suspended mineral solids and *E. coli* and suggested the reaction can be important in the removal of bacteria from natural, turbid waters.

The sorptive properties of soil minerals have been studied in considerable detail by agronomists. They have been especially interested in " phosphate fixation " - - a process in which a part of the phosphorus applied to fields in fertilizers reacts with mineral components and is made unavailable to plants during photosynthesis. SCARSETH (1935), SIELING (1946), MURPHY (1938), and MCAULIFFE *et al.* (1947) are only a few of the contributors to the literature of this subject in which various aspects of the fixation process have been described and mechanisms for the observed reactions given.

Estuarine environments have characteristics which should permit a wide range of adsorptive phenomena to take place. Drowned river and coastal plain estuaries usually are turbid and are more fertile than adjoining rivers and open ocean regions. In these regions the sorption of phosphate onto suspended solids and bottom deposits may have a position in the ecology of the region analogous to " phosphate fixation " in the terrestrial system.

We have had two opportunities to examine the suspended solids-phosphate system. The first was during field operations in the lower Chesapeake Bay and in the estuarine regions of the James, York, and Rappahannock Rivers (CBI Report No. 1). Measurements of total and dissolved inorganic phosphate and of turbidity were made on 176 samples taken at 30 stations in the region. The second, was during a laboratory

study of the uptake of dissolved phosphate, iodide, sulphate, copper (II), strontium, and iron (III) by several natural and synthetic solids (CARRITT and GOODGAL, 1953). In the latter studies radio tracer techniques were used to follow the sorption reactions. The results of these two studies are given below.

THEORETICAL

In this discussion the term *sorption* is used to denote any reaction between a solid and a dissolved substance. *Adsorption* signifies a unique process, one in which a tendency for the free energy of the solid surface to decrease, results in an accumulation on the solid surface of some environmental constituent at a greater concentration than exists at a distance from the surface. *Absorption* is the process by which solids take up a portion of solution much the same as a sponge takes up water. GLASSTONE (1940) gives a general discussion of these processes.

Many adsorption reactions have been described by empirical relationships called adsorption isotherms. These are usually equations which give the ralationship between the equilibrium concentration of the substance being adsorbed and the quantity of substance adsorbed per unit mass of adsorbing solid. KUNIN and MEYERS (1950) have discussed several adsorption isotherm expressions noting the kinds of systems to which they apply. Important to note here is that all such expressions are empirical. This prompted BRUNAUER (1945) to note that," - - it (an adsorption isotherm expression) gives a concise analytical expression for the experimental facts, rather than a clear cut picture of the mechanism of adsorption." In the following discussion adsorption isotherms will be used primarily as a convenience in describing and comparing observations.

The classical or Freundlick adsorption isotherm is one of the oldest and perhaps the most general of these relationships. It has the form :

$$(1)\quad x/m = kc^{1/n}$$

where c = the equilibrium concentration substance being adsorbed.
x = amount of substance adsorbed.
m = mass of adsorbing solid.
k and n = constants.
Taking logarithms the equation becomes :

$$(2)\quad \log x/m = \log k + \frac{1}{n}\log c$$

A plot of log x/m against log c should be a straight line and the constants can be obtained from the slope and intercept of the curve.

Many systems that have been studied " follow the Freundlick isotherm." However, usually if the ratio of concentrations of adsorbing solids to substance adsorbed is varied over a wide range deviations from predicted behaviour are found. This is to be expected, for, as has been frequently noted, the Freundlick relation predicts an unreasonable situation - - infinite adsorption capacity of the solid. Despite this limitation the relationship has been useful.

FIELD STUDIES

CBI report No. 1 (1949) contains the raw data that will be used here. Turbidity values were obtained by measuring the percent transmission of a 10 cm Corex cell containing a sample of untreated water, in a Beckman Model DU spectrophtometer. Values at 700 mμ are used here. Distilled water was used as a reference. Turbidity is reported as extinction (optical density), a quantity that can be calculated from percent transmission and is directly proportional to the concentration of light-attenuating substances. Dissolved inorganic phosphate was determined by the ceruleomolybdate method using stannous chloride as reducing agent. No " salt

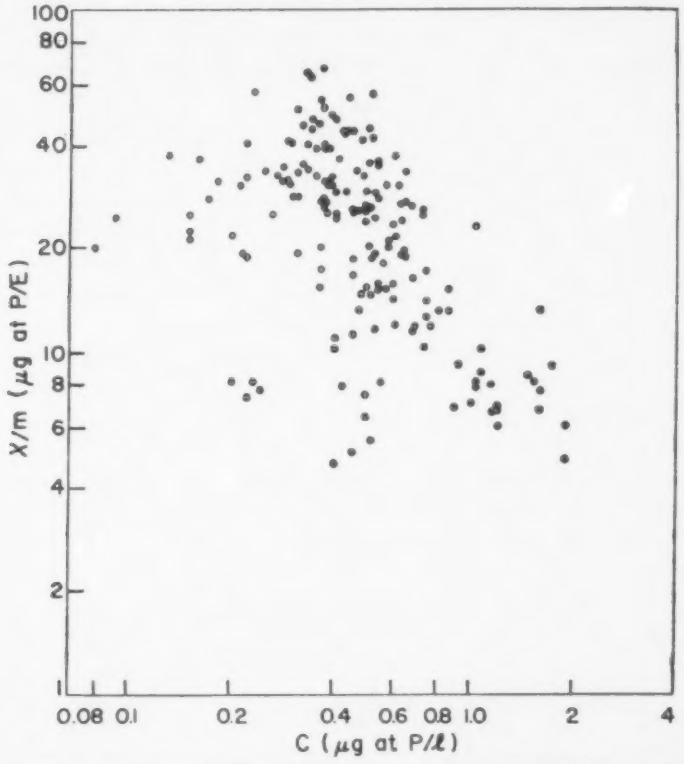

Fig. 1. Scatter diagram of log c plotted against log x/m. Data from field observations. The units of x/m are microgram atoms phosphorus per extinction unit. Extinction is proportional to the concentration of suspended solids.

error " corrections have been made. Total phosphate was determined by an acid-peroxide oxidation of a water sample and its associated solids, followed by the ceruleomolybdate procedure for inorganic phosphate. Turbidity and inorganic phosphate measurements were made within two hours after the sample was taken. Total phosphorus was determined on stored samples.

These data have been examined for a fit to the Freundlick adsorption isotherm. For this purpose it has been assumed :

(a) dissolved inorganic phosphorus provides a measure of the c term in the isotherm,

(b) the x term is given by total phosphorus minus dissolved phosphorus, and

(c) m corresponds to the extinction values obtained as a measure of turbidity.

A plot of log c against log x/m is shown in Fig. 1.

It is obvious that the data are not described by the Freundlick relation. A discussion of these data will be given later.

LABORATORY STUDIES

The methods used in the laboratory to study the uptake of dissolved substances by suspended solids were relatively simple. In general, solutions of test substance containing tracer quantities of radio isotopes at known specific activity were combined with suspensions of known concentration. The resulting mixture was placed in a shaking machine to prevent settling of the solids and at stated time intervals samples

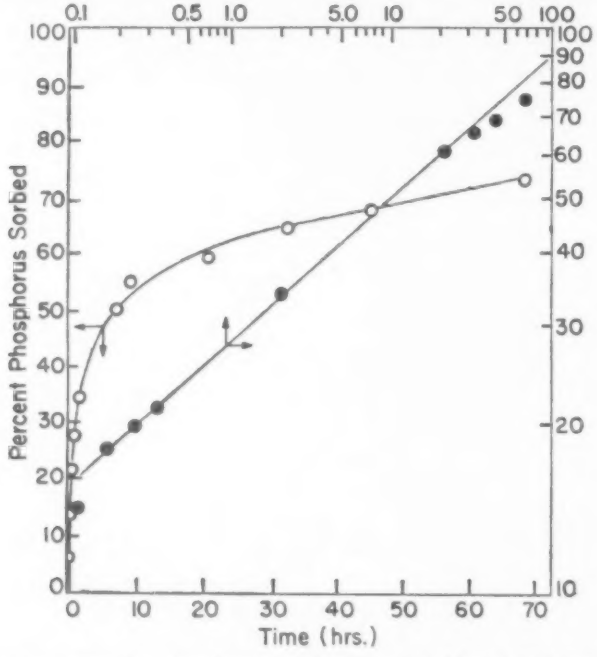

Fig. 2. Sorption-time curve for phosphorus solids system. Arithmetic plot open circles, left and bottom coordinates ; log-log plot, closed circles right at top coordinates. Initial conditions ; temperature 21°C, phH 3·4 solids 310 ppm, total phosphorus 3·4 μ g-at P/l.

were withdrawn for analysis. In all experiments temperature, pH, concentration of reacting substances, and concentration of nonreacting substances, were either controlled or measured. Several of the solids examined, samples from Chesapeake Bay cores, were characterized by X-ray diffraction and electron micrograph analyses, which provided information concerning the mineralogy and particle size distribution of the samples. We are indebted to Mr. MAURICE POWERS of the geology group at the Chesapeake Bay Institute for furnishing us with analyzed Bay solids.

Upon being withdrawn from the reacting mixtures aliquots were immediately centrifuged and both the supernatant solution and the solids were examined for

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radioactivity. From the results of these analyses the fraction of the test substance originally in solution that had been sorbed onto the solids was calculated. Analysis of both the solids and supernatant solution also furnished a means of checking the reliability of the method and gave an indication of the extent of side reactions, especially sorption onto the walls of the reaction vessel.

The solids examined consisted of six samples from Chesapeake Bay cores, a sample of Roanoke River mud, samples of commercial bentonite and Fullers Earth, and powdered pyrex glass. The solids were separated in several size fractions by sedimentation techniques, a procedure which in the case of the natural solids also produced a partial separation of the mineral components.

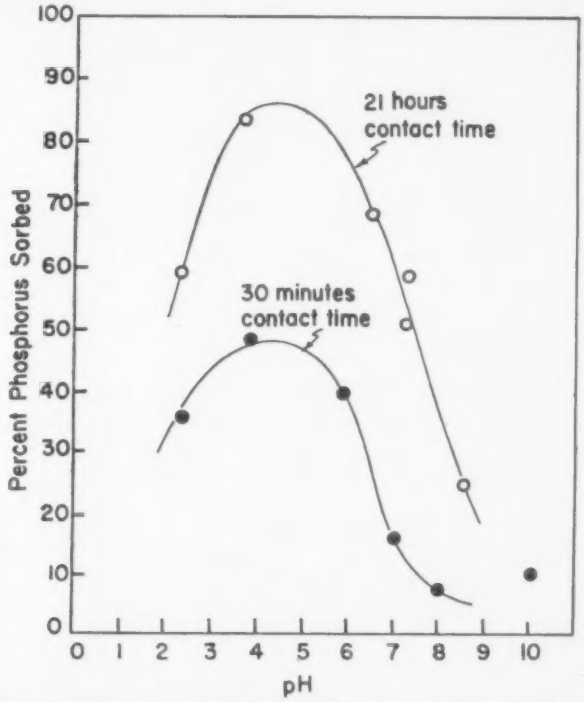

Fig. 3. Removal of phosphate by Roanoke River Solids as a function of pH. Initial conditions ; temperature 21°C, solids 310 ppm, total phosphorus 0·5 μ g-at P/l.

Phosphorus studies. The behaviour of the phosphorus – solids system was measured over wide variations in pH, temperature, concentrations, and time of contact. Several systems were followed by both colorimetric and radioactive phosphorus analyses. The double analyses were performed to provide the means of distinguishing between sorption and isotopic exchange reactions.

The behaviour of the systems as a function of time of contact is shown in Fig. 2, which is a combined arithmetic (bottom and left coordinates) and log-log plot (top and right coordinates) of the percentage of the phosphorus initially in solution that had been removed by the solids, as a function of time of contact.

The linear log-log relation is a characteristic common to all of the solids – phosphorus suspensions measured. Obviously this cannot be a general relationship that

will describe all systems regardless of solids to phosphorus ratio, for, except for the curve having zero slope, it predicts infinite capacity of the solids. Departure from linearity can be seen after contact time of more than 20 hours in Fig. 2. A system with a ten-fold increase in the phosphorus to solids ratio showed no departure from the linearity for 17 hours. A similar relationship has been reported in several

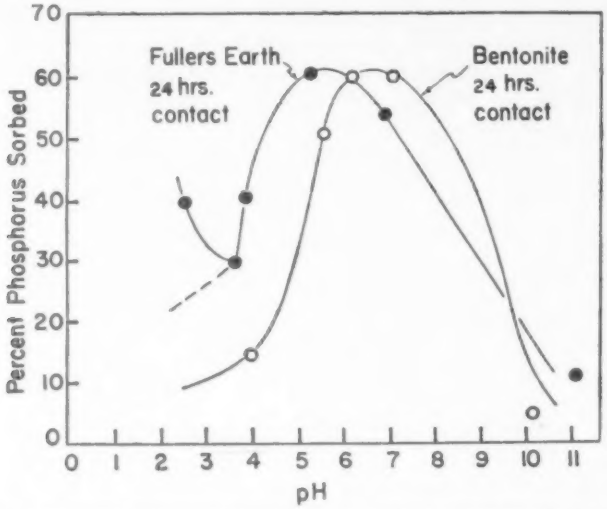

Fig. 4. Removal of phosphate by bentonite and Fullers Earth as a function of pH. Initial conditions, temperature 21°C, bentonite 800 ppm, Fullers Earth 756 ppm, total phosphorus 0·6 μ g-at P/1.

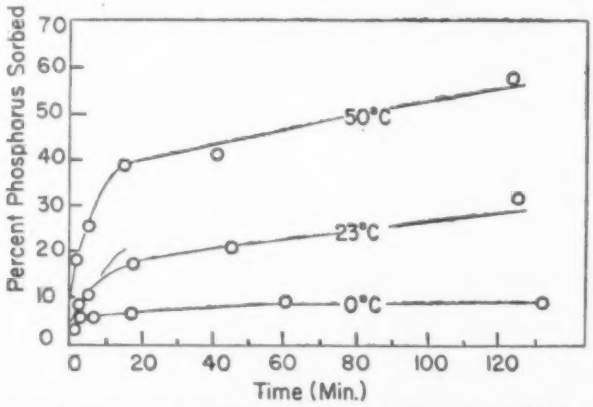

Fig. 5. The effect of temperature on the solids-phosphate sorption reaction. Initial conditions ; pH 3·8, solids 310 ppm, total phosphorus 2·2 μ g-at P/1.

studies in which phosphate fixation by tillable soils was measured. Although an empirical relationship and one which apparently does not follow from classical kinetics studies, the linear log-log relationship is useful as an interpolation expression.

The effect of pH on the uptake of phosphorus was measured in the range pH 2 to 10. Fig. 3 summarizes the results obtained using a sample of Roanoke River sediment, and Fig. 4 the results obtained using suspensions of bentonite and Fullers

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Earth. A comparison of these curves with phosphoric acid dissociation curves indicates that maximum uptake occurs in the pH range in which the singly charged H_2PO_4 ion is the predominent species.

The effect of temperature on sorption was measured by following the uptake reaction at 0°, 23°, and 50°C. The results are shown in Fig. 5. In addition to illustrating the marked effect that temperature can have on the sorption reaction in nature, the data can be used to evaluate the heat of reaction, a quantity which gives a measure of the stability of the solids-phosphorus complex. Evidence will be presented later which suggests that the uptake process proceeds via a rapid adsorption process and a much slower diffusion controlled reaction. Both of these processes were taking place during the course of the reaction and the data do not permit an evaluation of the contribution of each to the total. However, the heat of reaction measured at any stage of the reaction is the sum of the contributions of all the processes taking place and so is a measure of the mean stability of all the complexes that may have formed.

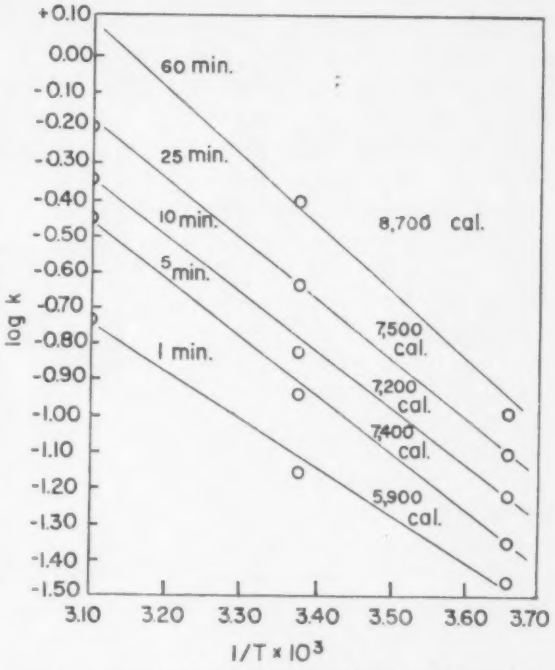

Fig. 6. Arrhenius plot for the phosphorus-solids sorption reaction. Initial conditions, pH 3·8, solids 310 ppm, total phosphorus 2·2 μ g-at P/l.

The heat of reaction was calculated from temperature dependence data and the Arrhenius equation :

$$d \ln k/dt = E/RT^2$$

which in integrated form is :—

$$\log k_1/k_2 = E/2{\cdot}303\ R\,(T_2\text{-}T_1/T_2\,T_1)$$

The heat of reaction, E, can be evaluated from measured values of the equilibrium constants at two or more temperatures. It is convenient to plot the logarithm of the equilibrium constants against the reciprocal of the absolute temperature and obtain the heat of reaction as the slope of the curve. This has been done and the results are shown in Fig. 6. The heat of reaction was calculated for 1, 5, 10, 25 and 60 minutes contact time. The agreement between the data and the linear relation predicted by the Arrhenius relation is satisfactory. The magnitude of the heat of reaction suggests that the initial phosphorus-solids complex is of limited stability. Heats of reaction of the magnitude reported here are characteristic of van der Waals adsorption (GLASSTONE, 1940, p. 1179).

Data were obtained for a test of fit to the Freundlick adsorption isotherm (Eq. 1). The sorption was followed in four systems in which the initial phosphorus to solids ratio was varied by a factor of ten but were otherwise identical. The results obtained from measurements taken at intervals during an hour's contact time are given in Fig. 7. In the range of concentrations studied the agreement appears satisfactory.

It will be noted that the *c* term in Freundlick isotherm is *equlilbrium* concentration. It is obvious from an inspection of Fig. 7 that the systems were not at equilibrium. Phosphorus was being lost to the solids during the entire period of measurement. The fact that a satisfactory fit to the isotherm equation was obtained for each of the sampling periods is interpreted as indicating that each of the systems, even after only one minute contact time, were at equilibrium with respect to an adsorption reaction and that loss of phosphorus from solution after adsorption equilibrium had been established was by some other process which proceeded slowly enough to not affect the equilibrium.

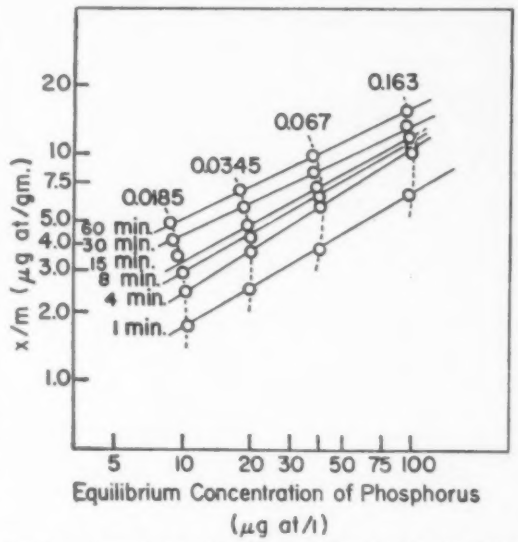

Fig. 7. Freundlick adsorption isotherms for the solids-phosphorus reaction. Initial conditions; temperature 23°C; pH 3·4; solids 620 ppm; phosphorus to solids ratio as noted. Units of ratio are μ g-at P/mg solids.

The extent to which phosphorus is accumulated on the solids particles is demonstrated by comparing the number of $H_2\ PO_4$ – ions in contact with an imaginary surface of unit area, with the number of ions on the same area of solids. In one of the isotherm test experiments a solution which initially contained 11·5 μ g-at P/l and 620 ppm of solids, was found to contain 10·4 μ g-at P/l after one minute contact time. In a solution containing 10·4 μ g-at P/l the average number of ions in contact with an imaginary plane will be $3{\cdot}4 \times 10^{10}$ ions/cm^2. The solids had an average diameter of 20 microns and a density of 2·6. It can be calculated that if the phosphorus lost to the particles were distributed as a monolayer on the solids there would be $9{\cdot}2 \times 10^{14}$ ions per square centimetre, or an accumulation of over 10,000 times that in the bulk of the solution.

The nature of the slow reaction that appears after adsorption equilibrium has been established, can be complex. Phosphate can react with several common mineral constituents. Phosphates of iron, aluminum, and calcium are insoluble, stable inorganic salts. Exchange reactions between phosphate and mineral constituents might occur, or, being accumulated on the surface, the phosphate might move into the voids in the structure of the solids. However, regardless of what the reaction is, the rate of the reaction can be no faster than the rate at which phosphate can get to the site of the reaction. It seemed reasonable, therefore, that this reaction might appear as a diffusion controlled reaction. The kinetics of diffusion generally follow

the parabolic diffusion law which states that the decrease in the concentration of a diffusing substance will be proportional to the square root of the time during which diffusion has taken place. The data used for the isotherm test were examined as a test of the diffusion hypothesis.

The driving force of the diffusion process is the phosphorus gradient in and near the adsorbed layer on the surface of the solids, a quantity not given directly by analysis – – analysis of the solids gives both the quantity adsorbed and that taken up by the slower process. In order to separate these quantities it was assumed that adsorption was complete after one minute contact time and the quantity at this time taken up by the slower process was insignificant. A solution was obtained for the one minute adsorption isotherm and using this expression and the measured values

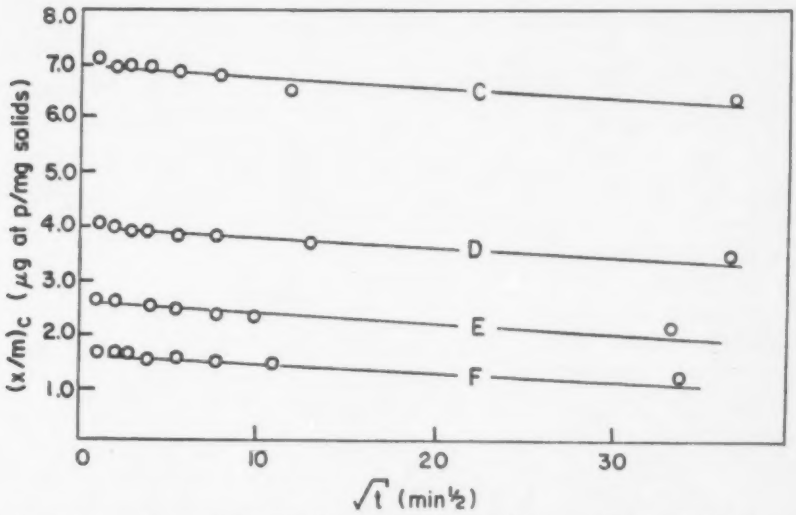

Fig. 8. Test of fit to parabolic diffusion law. Initial conditions ; pH 3·4 ; solids 620 ppm ; temperature 23°C ; phosphorus curve C 101, D 41·5, E 21·5 and F 11·5 μ g-at P/1.

of c, the equilibrium concentration of phosphorus, a value of $(x/m)\ c$ was calculated. $(x/m)\ c$ represents the conditions that would have existed had no phosphorus been taken up by the slower process. The quantities $(x/m)\ c$ are proportional to the driving force of the slower reaction and a plot of $(x/m)\ c$ vs $(t)^{1/2}$ should be linear if the reaction is diffusion controlled. The results are shown in Fig. 8. The slopes of the curves are $-0{\cdot}015$, $-0{\cdot}014$, $-0{\cdot}019$ and $-0{\cdot}015$ with a mean slope of $-0{\cdot}016\ \mu$ g-at P/1, $\text{min}^{-1/2}$. The general diffusion equation is :—

$$(C_0 - C_1) = 0{\cdot}016\ (t_0^{\frac{1}{2}} - t_1^{\frac{1}{2}})$$

where

C_0 = concentration (μ g-at P/1) in the diffusion layer at time t_0. Time is in minutes.

C_1 = concentration (μ g-at P/1) in the diffusion layer at time t_1.

A schematic representation of the uptake process is shown in Fig. 9.

The uptake of phosphorus was measured in sea water systems with salinity 17 and 34‰. The results are shown in Fig. 10. The removal of phosphorus from solution is seen to be less in sea water systems than in fresh, although the reduction in uptake is not in direct proportion to the salinity. This behaviour may be partially accounted for by the agglomeration of the solids, noted especially at salinity 34‰. The clumping of the finely dispersed solids to produce larger particles would result in a reduction in the surface area available for adsorption. Furthermore, in other experiments in which the uptake of sulphate was studied, the addition of phosphate was seen to reduce the sorption of sulphate by the solids, indicating a competition between sulphate and phosphate.

From an ecological point of view the stability of the solids-phosphorus complex is important. The movement of suspended solids together with their associated sorbed substances through regions of varying pH, temperature, and salinity, as, for example, during their passage from rivers through estuaries into the sea suggests the possibility of a removal – transport – regeneration mechanism, provided the sorption complex is of such limited stability as to be broken by the changing environmental conditions. The sorption mechanism that has been proposed, that is, a rapid adsorption reaction followed by a much slower diffusion controlled process, suggests that during desorption both the amount of phosphorus and the rate of removal from the complex will depend upon the length of time the complex has had to form. With long contact time a greater fraction of the phosphorus will have diffused into the solid and so will be slower to return to solution when environmental conditions change in a direction favouring desorption.

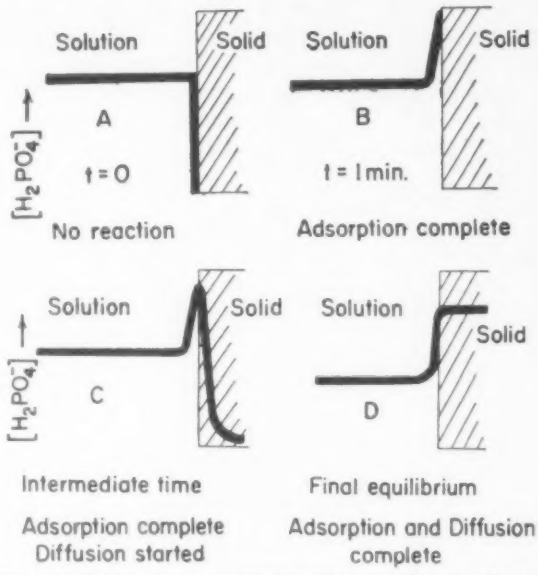

Fig. 9. Schematic representation of the mechanism for the up-take of phosphorus by solids. Solid line is the relative concentration of H_2PO_4-in the bulk of solution, in the adsorbed layer, and in the solid.

The results of two experiments illustrate the effect of contact time on the rate of desorption of phosphorus. Two samples of solids containing nearly the same total phosphorus were successively resuspended and centrifuged from phosphate free solutions. Each of the supernatant wash solutions was analyzed for phosphorus. One of the solids had been in contact with a phosphate solution for 4 days prior to the desorption experiment and the other for 30 minutes. The results obtained for six two minute wash cycles are shown in Fig. 11. The results are in agreement with the hypothesis that the complex formed after long contact time is less susceptible to rapid regeneration of the phosphorus than the complex formed during short time

contact. The results of a similar experiment but covering longer times of contact are shown in Table I.

Table I.

The effect of time of formation on the short time availability of phosphorus from a solids-phosphorus complex

Prior contact time	*Percent phosphorus regenerated*
26 min.	42·9
18 hrs.	23·9
48 hrs.	17·9
5 days	18·0
7 days	14·1

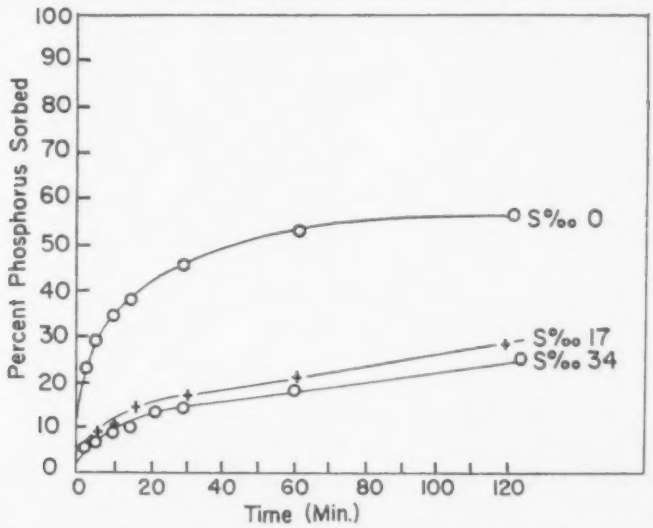

Fig. 10. The effect of variations in salinity on the uptake of phosphorus. Initial conditions ; pH 3·4, solids 310, phosphorus 0·9 μ g-at P/l, salinity as noted.

Attempts were made to measure the effect of particle size and of mineral composition of sediments taken from Chesapeake Bay on the sorptive properties of the solids. The measurements were inconclusive. Separation of the solids into various size fractions by sedimentation techniques also produced a fractionation of the mineral components of the solids, probably because of their slightly differing densities. No correlation between measured sorptive properties and mineral analysis was found. Five samples of Bay solids tested had the following range of composition : kaolinite less than 5% to 15% ; illite less than 10% to 40% ; chlorite-like montmorillinite 20% to 90% ; amorphus silica less than 5% to 35% ; quartz less than 5% to 20%. Generally, the solids having large amounts of quartz showed a low ability to sorb phosphorus. This is in agreement with sorption measurements on sand and on powdered pyrex glass. These solids had a much lower sorption capacity than the other solids tested. Measurement of the specific sorption capacity of purified samples of each of the mineral components found in the sediments might permit à rationalization of the measurements made on mixtures.

A summary of a series of experiments carried out with the natural solids under nearly the same environmental conditions is given in Fig. 12. All of the systems represented here were measured at room temperature, in the pH range 3 to 6, and $S = 0‰$. The coordinates are percent phosphorus removed and ratio of initial phosphorus concentration (μ g-at P/l) to solids concentration (ppm). The envelope between the two curves contained all the points obtained with Roanoke River solids

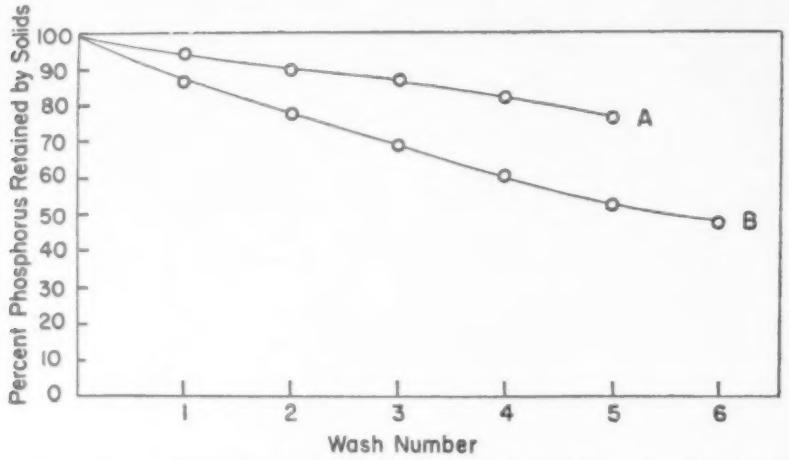

Fig. 11. The effect of prior contact time on the desorption of phosphorus from solids. pH of wash 3·4 A. 4 days contact ; B.30 minutes contact.

for contact time of from 1 min to 24 hours. The points tied together by vertical lines are from single determinations on the several Chesapeake Bay solids. The upper point of each pair is the 24 hours contact time measurement ; the lower one, the 1 minute contact time.

The uptake of strontium, iodide, copper (II), iron (III), and sulphate suphur was measured, using samples of the same solids as in the phosphorus studies. Since these substances are not major metabolites only a brief summary of their behaviours will be given here. It should be noted however that the classification as major and minor constituents is on a concentration basis and may not reflect the importance of a substance in the nutrition of aquatic organisms. It may be that the processes affecting the distribution of the so called minor constituents are as important to the ecology of a region as those which affect the major constituents.

Strontium. Details of the studies with strontium and possible applications of the observed behaviour to the decontamination of radioactive wastes, have been given elsewhere (GOODGAL, *et al.* (1954)).

SVERDRUP *et al.* (1942) mention the presence of strontium carbonate in certain Radiolaria. The similarity of the chemical behaviour of calcium (a major metabolite) and strontium suggests that the behaviour of the former may in some respects parallel that of strontium.

Two kinds of reactions were found to be important in the removal of strontium from solutions containing suspended solids. In solutions in which the solubility product of strontium carbonate was not exceeded (low pH, small strontium ion

concentration, or carbonate free solutions) strontium was adsorbed onto added solids and during a hundred fold change of initial strontium to solids ratio the behaviour followed the Freundlick adsorption isotherm expression,

$$x/m = 0{\cdot}0032\ C^{0{\cdot}44}$$

where the units of x/m are μ g-at Sr/mg and C are μ g-at Sr/1. The solutions examined contained from 52 to 5,200 μ g-at Sr/1, 728 ppm added solids and were essentially carbonate free.

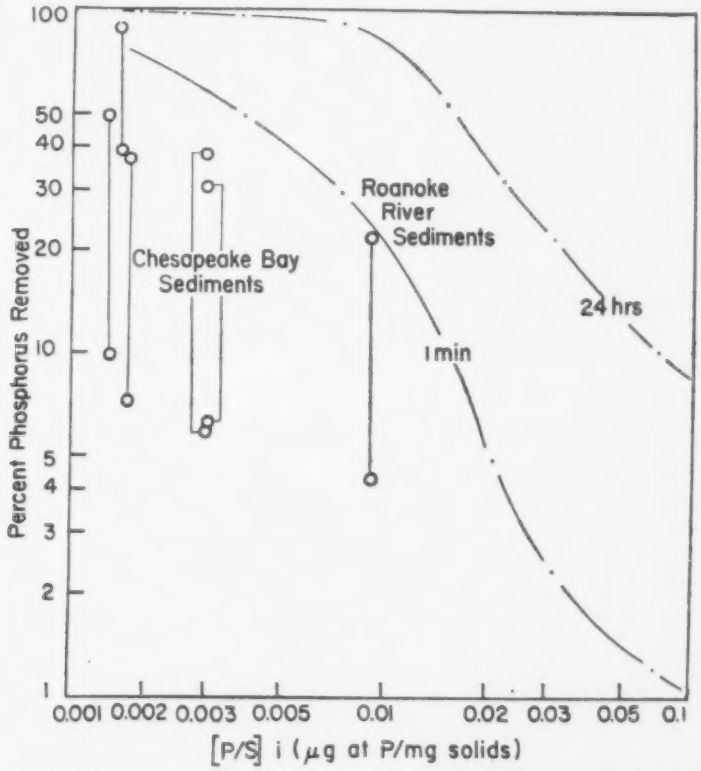

Fig. 12. Summary of sorption reactions of phosphorus onto Roanoke River and Chesapeake Bay solids. Units of the abscissa (P/S)i are the ratio of the initial phosphorus concentration (μ g-at PL/1) to the solids concentration (ppm).

In solutions in which the solubility product of strontium carbonate was exceeded the behaviour followed closely that which was predicted from a consideration of the solubility product, the pH, and the dissociation constant expressions of carbonic acid.

Iodide. The sorptive capacity of the solids tested for iodide was very low. Measurable uptake was obtained only from carrier-free solutions of I^{131}. No uptake could be measured from solutions containing 1 ppm of added inactive iodide. Using carrier-free solutions which contained approximately 3×10^{-7} ppm iodide and 983 ppm added solids the pH dependance was measured in the range 3·3 to 10·8

for 24 hours contact time. A bimodal curve, with maxima at pH 3·3 and 6·6, 9·1% and 9·2% removal respectively, resulted.

Sulphate. The removal of sulphate by sorption onto added solids was measured using S^{35} labelled sulphate. The effect of pH on the sorption reaction is shown in Fig. 13. The behaviour suggests that the bisulphate ion (HSO_4^-) is the most sorbable dissociation product, as maximum uptake occurred in the pH range which

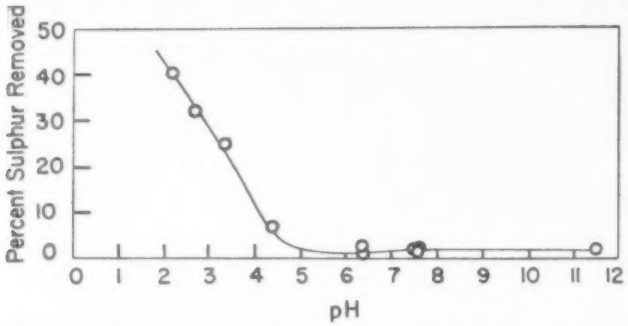

Fig. 13. The removal of sulphate by Roanoke River solids as a function of pH. Initial conditions : Solids 760 ppm, sulphate carrier free S^{35} approximately 1,000 cpm/ml, contact time 30 min.

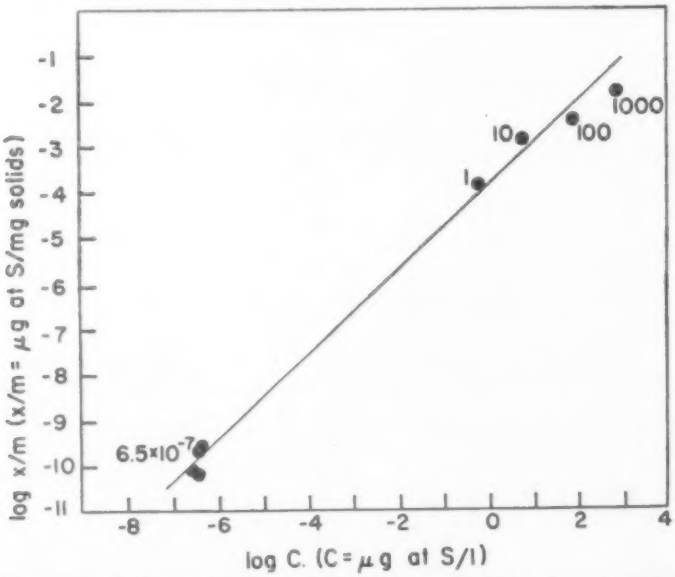

Fig. 14. The Freundlick Adsorption Isotherm for the uptake of sulphate onto Roanoke River solids. Initial conditions ; pH 3·3, contact time 20 min., total sulphur as noted. Added solids in the range 75 to 2,500 ppm.

favours its formation. In this respect the behaviour of phosphate and sulphate are similar – the active ions in both cases are the monovalent species.

The temperature dependance of sulphate sorbtion was measured at five temperatures in the range 0° to 60°C. The observed temperature coefficient was negative and small, being only little more than experimental error.

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The fit of experimental data to the Freundlick adsorption isotherm is shown in Fig. 14. The expression for the best visual fit is :—

$$x/m = 0{\cdot}0013\ C^{0{\cdot}92}$$

in which the units of x/m are μ g-at S/mg and of C are μ g-at S/l.

The fit of the data to this isotherm is only fair. However, it should be noted that the range of the concentration of initial sulphate varied by a factor of 1,000 million (10^9).

The stability of the sulphate – solids complex was measured in desorption experiments similar to those conducted with the phosphorus system. Washing with sulphate-free solutions returned much of the sorbed sulphate to solution. For example, 66·2% of the sorbed sulphate was removed by washing at pH 2·5, 77·4% at pH 4·5, and 84·3% at pH 9·0.

Iron. The sorption of iron (III) onto solid was measured in the pH range 3 to 10. The results are shown in Fig. 15. The shape of the curves suggests that at least two processes are involved in the observed reaction. The precipitation of hydrous ferric oxide undoubtedly accounted for some removal of iron. The curve calculated from the solubility product, $(Fe)\ (OH)^3 = 10^{-36}$ is included in Fig. 15. The minimum in the uptake curve at approximately pH 7 may be associated with the behaviour of the suspended solids at the isoelectric point. Further experiments were not conducted however to clarify this point.

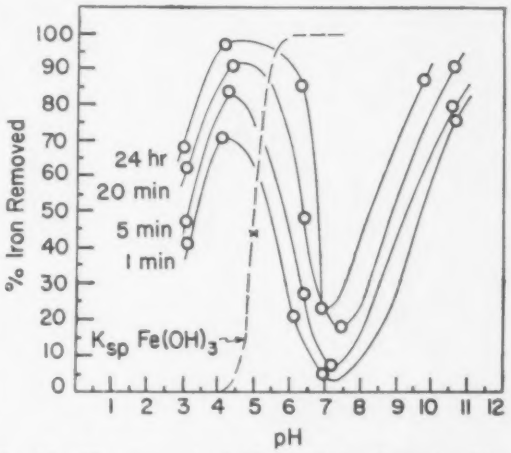

Fig. 15. The removal of iron (III) by Roanoke River solids as a function of pH and contact time. Initial conditions, Fe (III), 0·02 μ g-at/l., solids 500 ppm.

With initial iron to solids ratio in the range of 2×10^{-2} to 5×10^{-4} μ g-at Fe/mg, sorption data gave a poor fit to the Freundlick adsorption isotherm expression.

The presence of citrate markedly reduced the uptake of iron.

Sorbed iron was readily removed from the iron-solids complex with iron free wash solutions at pH 2·0, but not at pH 4·1.

The presence of sodium chloride in the range 0 to 6% had no effect on the uptake of iron for contact periods greater than 24 hours. With shorter contact time, up to 1 hour, sodium chloride suppressed sorption.

Copper. The removal of copper by added solids was measured in the pH range 3 to 12. In all of several experiments a marked maximum was observed at pH 6 to 8. An attempt was made to differentiate between precipitation of cupric hydroxide and sorption on the added solids by measuring the amount of copper removed by centrifugation in two series of experiments indentical except that to one solids were added, to the other no solids were added. The results are shown in Fig. 16. Included in the figure is a curve calculated from the solubility product of cupric hydroxide,

(Cu) $(OH)^2 = 5{\cdot}6 \times 10^{-20}$ (LATIMER, 1938). Unquestionably added solids aid in the removal of copper (II). The results shown in Fig. 16, however, do not conclusively differentitate between precipitation and adsorption. It is possible that the added solids acted merely as a "sweeper" which entrapped colloidally dispersed cupric hydroxide that could not be centrifuged from solution.

Additional information concerning a possible adsorption reaction was obtained by studying the uptake of copper by two systems in which the ratio of initial Copper (II) to solids was varied. The pH of one series of experiments was 3·3, low enough to prevent precipitation of cupric hydroxide. The second series was at pH 7·8. The results are shown in Table II. In each case the removal of Copper (II) increases as the copper-solids ratio decreases, a result not to be expected if the solids acted only as a mechanical sweeper.

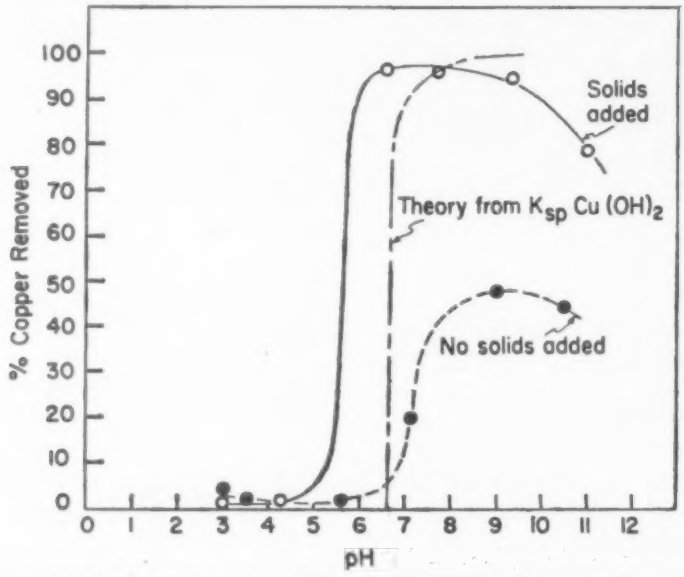

Fig. 16. The removal of Cu (II) by precepitation as Cu $(OH)_2$ and by sorption on added solids. Initial condition, Cu (II) 32·5 μ g-at Cu/l, solids 360 ppm, contact time 20 minutes.

Table II

The removal of copper (II) *with varying copper-solids ratio at pH* 3·3 *and* 7·8. *Contact time* 1 *hour.*

pH = 7·8		pH = 3·3	
[Cu/S]i	*% Removed*	*[Cu/S]i*	*% Removed*
7·8	10·0	3·1	4·6
0·8	57·6	0·3	6·1
0·3	87·9	0·1	9·1
0·1	84·8	0·008	10·0

The results from the two series of experiments just described were tested for fit to the Freundlick adsorption isotherm. At pH 3·3 good agreement was obtained. At pH 7·9 the agreement was only fair.

DISCUSSION

The results obtained from the field measurements of the phosphorus-solids system, shown in Fig. 1, certainly are inconclusive. No decision can be made concerning the existence of an adsorption reaction between the suspended solids and the dissolved phosphorus. If such a reaction is involved its effects are masked by the presence of other reactions which have disturbed the adsorption equilibrium or by sources of phosphorus or turbidity not involved in a sorption reaction. Several hypotheses can be advanced, any one of which appears to " explain " why the observed results are as they are. The assumed distribution of total phosphorus between sorbed and soluble fraction undoubtedly is unreal. The analytical method for total phosphorus measured the amount of phosphorus present in living and dead organic matter as well as the amount coming from insoluble inorganic phosphates. Phosphorus so combined probably is not available to sorption reactions. Sampling a variable distribution of plankton might then account for some of the observed scatter. The inability of an optical method of turbidity analysis to give an unambiguous measure of the concentration of suspended solids in suspensions containing particles of varying size and refractive index undoubtedly produced anomalies. The effects of variations in temperature, salinity, and pH were neglected in treating the field data. Although several of these effects were anticipated no convenient way of measuring them in the field could be found. Thus, field measurements of the kind reported here appear unsuited to the problems of demonstrating sorption reactions and their importance in aquatic systems.

Measurements of the solids-phosphorus system in the laboratory, where many of the masking effects present in nature could be eliminated or controlled, provide a much clearer picture of sorption properties of one fraction of the solids that are normally found suspended in the water. It should be pointed out, however, that the results of these laboratory measurements cannot be transferred quantitatively to the field situation, for, although some of the experimental solids had at one time been natural turbidity components, the laboratory measurements were on static systems, and the effects of continuous and simultaneous changes in temperature, pH, salinity, etc., were not obtained. The results of these static measurements do, however, permit a qualitative evaluation of the extent to which mineral turbidity components may remove dissolved substances from solution.

The behaviour of the phosphorus-solids system is the most striking of those studied in the laboratory, both from the point of view of quantity of subtsance removed from solution per unit weight of adsorbing solids and of the variability imparted to the system by changes in environmental conditions. The reversible nature of the reaction is important in ecological considerations and may require a modification of the interpretation usually given to the result of colorimetric analyses for phosphate in turbid samples. The sorption complex acts as a reservoir of phosphate from which phosphate can be withdrawn as other phosphate-consuming processes remove it from solution. The relationship between the sorption complex and the dissolved phosphate is in many ways analogous to a buffer system containing an undissociated weak acid, the anion of the acid, and hydrogen ions. Colorimetric methods of phosphate analysis in turbid waters require the removal of suspended solids prior to analysis. Thus, a fraction of the available phosphate is removed with the solids and is therefore not seen by the method. The results, while reporting the amount of phosphate actually

in solution, must be low when considering the quantity available to photosynthesis.

The behaviour of the sorption complex with variations in temperature, pH, and salinity indicates a possible mechanism of removal, transport, and regeneration of phosphate, which emphasizes the importance of suspended mineral solids and bottom sediments as ecological factors. Bottom deposits under fresh water frequently become anaerobic and acid during summer stagnation. Under these conditions the phosphate released during decomposition of organic debris is in an environment favouring the formation of a solids-phosphorus complex, as maximum uptake was shown to occur in the pH range 4 to 6. The effect here then is to trap phosphorus in the bottom deposits, and opposes the regeneration of soluble phosphorus associated with the reduction of ferric phosphate under anerobic conditions, as has been postulated by HAYES and COFFIN (1951). The return of phosphorus to solution from a sorption complex is favoured by an increase in pH which can take place during spring and fall turn over. In confirned fresh waters the vertical circulation accompanying turnover can carry the smaller sediment particles toward the surface and into water of high pH, thus liberating a part of the sorbed phosphorus.

Coupling the properties of the phosphorus-solids complex with the changes in environmental properties associated with water as it flows from rivers through estuaries into the sea, the enchanced fertility of estuaries, compared with adjoining fresh water and marine regions, appears as a natural consequence. Low salinity and pH, and high turbidity of the fresh river waters favour the formation of the sorption complex. Phosphate is furnished to these waters by run off from land, especially in regions where the land is tilled and fertilized. In estuaries mixing of these waters with sea water presents an environment of higher salinity, pH and concentration of competing ions, thus favouring the regeneration of phosphate, making it available to phytoplankton during photosynthesis. A part of the phosphate carried by the solids, that in the adsorbed layer, is immediately available to regeneration ; another part, that which has diffused into the solids, is available only after much longer contact with the changed environment.

It should be noted that many dissolved substances compete in sorption reactions. For example, the presence of phosphate was shown to reduce the uptake of sulphate. Similarly the desorption of phosphate, favoured by an alkaline medium, can be considered to be competition of hydroxide and phosphate. Thus, in order to obtain quantitative information concerning the extent to which a given dissolved constituent is bound up in a solids complex one must know the composition of the solution with respect to competing substances as well as the relative stability of all the possible sorption complexes.

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A preliminary note on the time scale in North Atlantic circulation

L. V. WORTHINGTON*

Summary—Recent observations show that the temperature and salinity relationship of the North Atlantic Central Water Mass has changed significantly during the fifteen year period 1935-1950. This evidence, coupled with a reassessment of certain budgeting problems which arise from the exclusive use of the circulation theorem, points to a rapid turnover of water from the surface to mid-depths. It is shown that the North Atlantic Deep Water has suffered a loss of oxygen in the last twenty years; from this it is surmised that the bulk of this water was formed during the period of catastrophic cold from 1810 to 1820.

A question of great importance to the understanding of the circulation of the oceans is that of how long a period has passed since a given water type has been in contact with the atmosphere. It has long been generally accepted that the cold water which fills the deeper portions of the ocean basins has been cooled by contact with the atmosphere in high latitudes.

In the North Atlantic, ISELIN (1939) has shown that a temperature-salinity curve (through the range 18° — 36·5‰ to 8° — 35·1‰) can be constructed from surface observations in late winter, along a North-South band in mid-Atlantic which differs only slightly from the temperature-salinity curve usually obtained from vertical observations (hydrographic stations) in large areas of that ocean. This led to the concept that this water mass is formed by contact with the atmosphere and that lateral mixing and large scale sinking of surface water along σ_t surfaces are responsible for maintaining the consistent T/S relationship.

While it is by no means clear how such sinking apparently continues through the summer months there are indications, apart from the consistency of the surface and subsurface Temperature-Salinity relationship, of the existence of such a mode of circulation. There is no serious doubt, for example, that the Gulf Stream System transports a large volume of water northwards across the 45th parallel, but if we are to believe solely in geostrophic circulation little of this water is returned to the south. It is possible to arrive at a rough estimate of the amount of water involved by computing the net northward volume transport between two stations, one on either side of the ocean, according to the geostrophic equation.

For purposes of this inquiry two composite stations were constructed from WÜST and DEFANT'S (1936) subsurface atlas of temperature and salinity, one at 46°N, 45°W close to Flemish Cap and one at 48°N, 10°W on the European continental slope off d'Ouessant. The northward volume transport (relative to the 2,000 decibar surface) between these two stations was computed by means of the geostrophic equation and found to be 38 million m^3/sec. If the Labrador Current carries 5 million m^3/sec. southward, to the west of a line drawn between the two stations there remain 30 million m^3/sec., or thereabouts, which the geostrophic equation

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is unable to account for since the pressure gradients below the 2,000 m level are so small as to be negligible.

Evidently this large amount of water disappears north of these stations as far as geostrophic circulation is concerned, and it is perhaps significant that roughly the same amount of water reappears in the Gulf Stream System as far as geostrophic circulation is concerned, between the Straits of Florida and Cape Hatteras. Many sources including WÜST (1924) and PARR (1937) agree that the volume transport of the Florida Current in the Straits (subject to short period variations) is about 25 million m^3/sec., and frequent sections from Montauk Point to Bermuda (ISELIN, 1940) have shown that there the volume transport of the Gulf Stream is about 72 million m^3/sec. If the Antilles Current adds 15 million m^3/sec. to the Florida Current north of the straits there remain 32 million m^3/sec. which must be added to the current by non-geostrophic means, presumably by horizontal flow along σ_t surfaces.

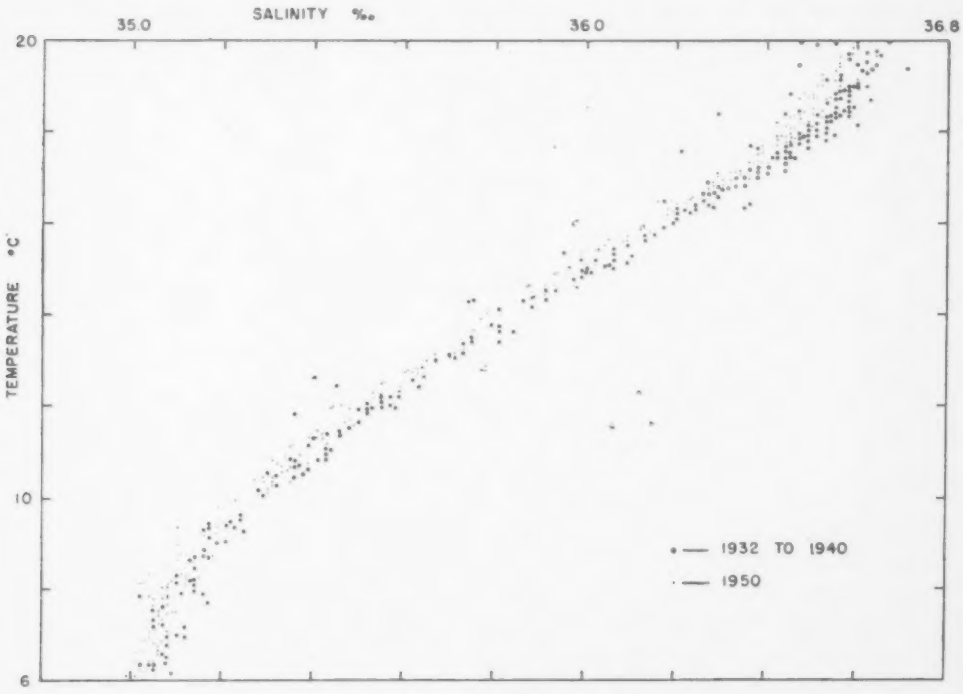

Fig. 1. Comparison between the temperature-salinity relationship of Gulf Stream Water in the years 1931-1940, and 1950.

In attempting to assign a time scale to this movement it must be admitted that only the crudest estimates can be made on the basis of existing data. While it is contended that the water types which join the Gulf Stream in this region were once at the surface and that they submerged in high latitudes, little is known of the path by which they returned to lower latitudes. In the Florida Current region an average figure can be given of the rate of westerly flow, across a line drawn between the Little Bahama Bank and a point 100 miles off Cape Hatteras, which must take place in order to add

30 million m^3/sec. to the current; this average figure is about 3 cm/sec., or 1·5 miles per day or 550 miles per year. It seems likely that this is a maximum figure for speed of flow of this type because here the width of flow is narrowest. The minimum distance from the region of surface convergence for, let us say, the 10° isotherm is 3,000 miles, which at the maximum rate could be travelled in 5½ years.

While this rate of turnover is almost certainly too swift, changes have recently taken place in the characteristics of the Sargasso Sea which indicate that it is not absurdly swift. In Fig. 1 a comparison is shown between the Temperature-Salinity relationship in the Gulf Stream in the years 1932-1940 and in 1950. Most of the stations included fall on the Montauk Point-Bermuda section, some of the earlier (1932-1933) stations are on the Chesapeake-Bermuda section.

In order to give a quantitative measure of the amount of this change Table I was constructed, by means of the salinity anomaly method. ISELIN'S (1936, Figs. 25 and 53) temperature-salinity curves for the Sargasso Sea were taken as normal. The average departure from these curves was computed for both the 1932-1940 and the 1950 Gulf Stream observations in 2°C steps, as follows:

Table I

Temp. Range °C	*Sal. Anom.* ‰ 1932-1940	*No. of Obs.* 1932-1940	*Sal. Anom.* ‰ 1950	*No. of Obs.* 1950	*Amount of Change (Fresher)*
18 – 16	0	75	0·04	44	0·04
16 – 14	+ 0·01	34	0·03	26	0·04
14 – 12	0	36	0·03	23	0·03
12 – 10	0	33	0·03	35	0·03
10 – 8	0·02	32	0·04	35	0·02
8 – 6	+ 0·01	31	0·01	33	0·02
6 – 4	0	79	0·02	127	0·02
4 – 2	0	84	0·01	105	0·01

The irregularities which appear in the anomalies of both periods are thought to be real, and are ascribed to the impossibility of drawing a smooth temperature-salinity curve which is absolutely exact. The cause of this freshening (if it is indeed freshening; the same anomalies would appear if the water became about 0·2° warmer at the same salinity) is beyond the scope of this study. It is merely brought up to illustrate the fact that a change has occurred in a short time period, which argues for a brisk turnover from the surface to mid-depths, a turnover roughly consistent with the rate computed above from transport figures. That the anomalies diminish to barely significant proportions in the deep (4° to 2°) water can be taken to mean that the apparent freshening cannot be charged to differences in the technique of analysis or in the Standard Water.

In the North Atlantic Deep Water there is evidence in the form of oxygen measurements which points to a more recent turnover than is generally supposed to have occurred. SEIWELL (1934) presented contours of the dissolved oxygen content of the western North Atlantic at various levels. His deepest chart (2,500 m) of the distribution of dissolved oxygen in ml./l. is reproduced here as Fig. 2. It is based principally on *Atlantis* cruises from 1931-1933 and the *Dana* cruise of 1921-1922.

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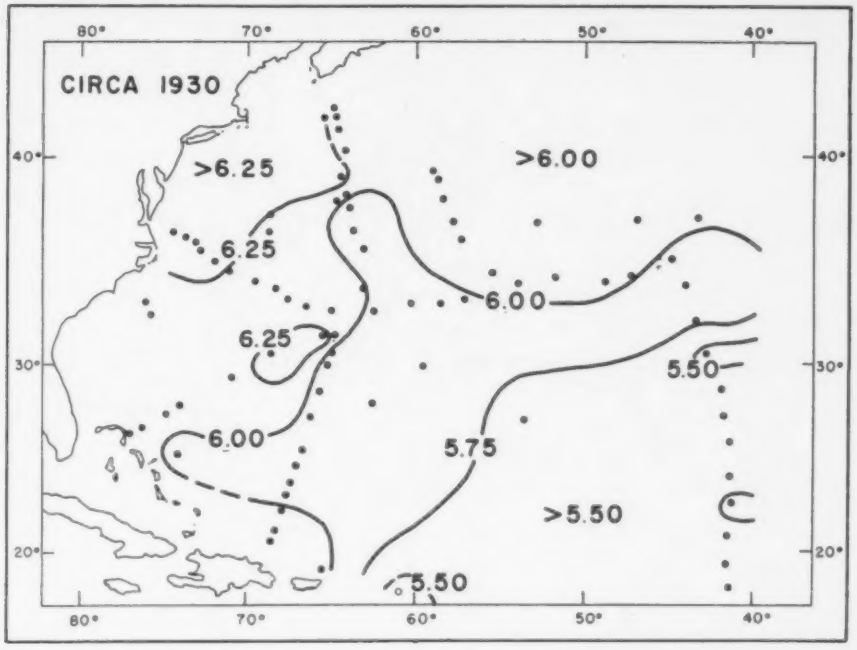

Fig. 2. Distribution of dissolved oxygen, ml./l., at the 2,500 m level, from SEIWELL (1934).

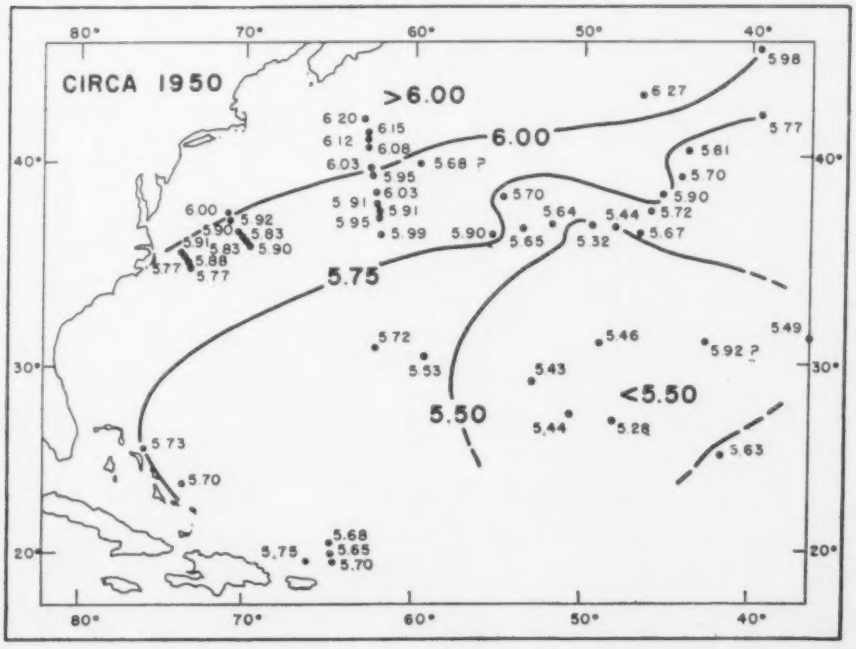

Fig. 3. Distribution of dissolved oxygen, ml./l., at the 2,500 m level, from *Atlantis* stations, 1947-1954.

For comparison is offered Fig. 3, based on *Atlantis* cruises from 1947 to 1954, which shows an average over-all drop in dissolved oxygen at the same level of about 0·3 ml./l. In individual stations taken during both these periods there is little change in the oxygen content of the water column vertically between 2,000 m and 4,500 m, which cannot be ascribed to the inaccuracies in the method of determination. Below 4,500 m water of South Atlantic origin begins to be found. In Fig. 4 are plotted four oxygen curves from stations north of the Greater Antilles, two from 1954, one from 1932, and one from 1922, which illustrate the loss of oxygen in that area.

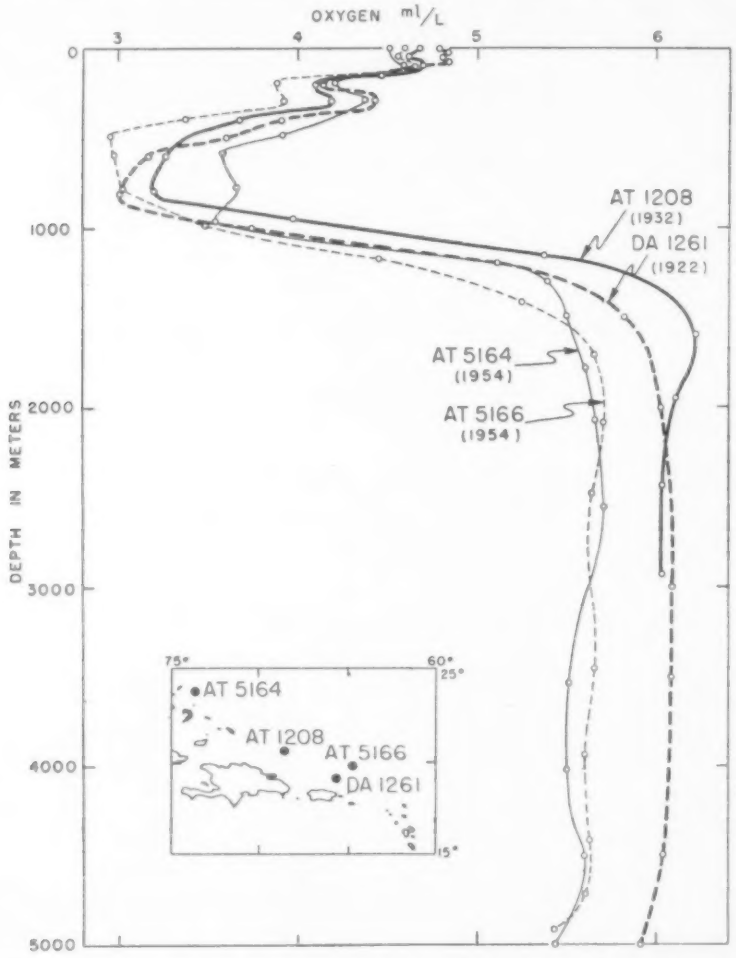

Fig. 4. Vertical oxygen curves illustrating the loss of oxygen in the North Atlantic Deep Water in the area north of the Greater Antilles.

Old and new data on the eastern side of the mid-Atlantic Ridge are not so plentiful, but they show that the deep water there has suffered a loss of oxygen comparable to that on the western side. In Fig. 5 are plotted the values of 0_2 in ml./l. at the 2,000 m level from the *Armauer Hansen* cruise of 1914 (GAARDER, 1927) and *Atlantis* stations

made in the years 1947 and 1948. Unfortunately, the *Armauer Hansen* data do not extend to depths greater than 2,000 m and so often fall in the gradient between the oxygen minimum layer and the oxygen-rich deep water. However, the comparison serves to show that the oxygen attrition is not confined to the western basin.

The *Atlantis* Mediterranean cruise of 1947-1948 is of particular interest to this study because during this cruise deep oxygen data were obtained in both the eastern and the western basins of the North Atlantic and in the Mediterranean itself. In both the Atlantic basins considerably lower values of oxygen content were found in

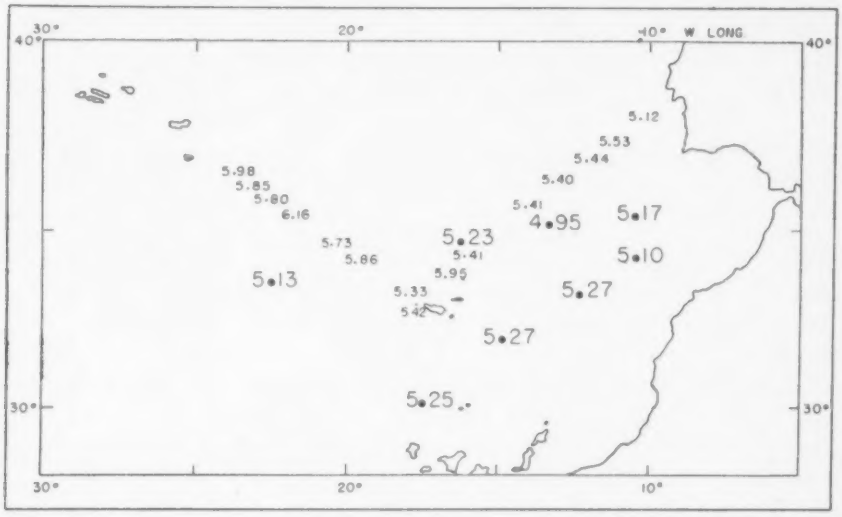

Fig. 5. Dissolved oxygen values, ml./l., at the 2,000 m level. Small figures are from the *Armauer Hansen* cruise of 1914 (GAARDER, 1927), the large figures are from *Atlantis* stations made in 1947-1948.

the deep water than in previous years, while in the Mediterranean POLLAK (1951) was able to contour deep oxygen values from *Dana* (1928-1930), *Thor* (1908 and 1910) and *Atlantis* (1948) observations, as if synoptically. The oxygen titrations were; performed in the same manner throughout this cruise. These data infer that the loss of oxygen in the North Atlantic Deep Water is real, and cannot be attributed to differences in the technique of analysis.

It appears from a comparison of Fig. 2 and 3 that in the western basin the loss of oxygen in the deep water has been roughly 0·3 ml./l. in twenty years, or 0.015 ml./l. per year. By assuming that this attrition has been going on at a steady rate it is possible to estimate by extrapolation the date at which this water was saturated with oxygen, presumably at the time that it was formed by atmospheric cooling. The date arrived at by this means is 1810.

The following sentences are quoted in this connection from WILLETT (1951): " At about 1800 there occurred a sharp reaction to lower temperatures which produced the severest cold on record in northern Europe, and coldness only slightly less severe in the northeastern United States. The famous ' year without a summer,' 1816, occurred during this period . . . " There exists a strong possibility that the bulk of North Atlantic Deep Water was produced during this catastrophe and that cooling

in high latitudes in more recent years has not been sufficiently severe to produce enough water of high density to replace it.

These data are hard to reconcile with the age determinations made on sea water by KULP (1953) by means of radiocarbon 14. KULP's table of ocean water age measurements is reproduced here :

Table II

Location	*Depth, ft.*	*Depth, m*	*Apparent age, yrs.*
13° 35′N, 66° 35′W	surface	surface	recent
19° 24′N, 78° 33′W	surface	surface	recent
41° 00′N, 54° 35′W	surface	surface	recent
38° 42′N, 67° 54′W	13,500	4115	450 ± 150
63° 46′N, 00° 26′W	10,440	3182	500 ± 200
34° 56′N, 68° 14′W	16,560	5047	1,550 ± 300
35° 46′N, 69° 05′W	15,300	4663	1,950 ± 200
58° 19′N, 32° 57′W	6,000	1829	1,600 ± 130
53° 53′N, 21° 06′W	9,100	2774	1,900 ± 150

However, it appears from the positions and depths of KULP's measurements that all the subsurface samples in Table II were taken on or close to the bottom where conceivably some exchange of carbon between the sea water and the older bottom sediments or limestone rocks might have taken place. Age determinations of water from mid-depths should prove most interesting in this connection.

In summary, if the layer in contact with the ocean bottom can be put aside for the time being, we can consider (with some oversimplification) that there are two types of turnover which take place in the North Atlantic. The first, which is taking place continually, consists in water being transported to high latitudes by geostrophic and returned to lower latitudes by sinking along σ_t surfaces. In this type of circulation no violence is done to the water's identity as a water mass, and its temperature and salinity relationship remains essentially unchanged. Such changes as do occur are probably the result of the ocean's rapid response to climatic changes, and should take a prominent part in the study of these changes.

In the second, a vast amount of water of a single or nearly single water type is formed in successive years of catastrophic cold at high latitudes. To perform this, many water types must be combined into one by large scale top to bottom mixing. The North Atlantic Deep Water which was seemingly formed in this manner has penetrated as far as 40° South and comprises about half of the entire contents of the North and South Atlantic Oceans. How much of this water was formed in the individual catastrophe of 1810-1820 is open to question, as is the possibility of tracing different portions of this water to climatic changes in the more recent or remote past. Such questions cannot be answered without repeated re-examinations of the oceans.

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Seamounts in the North America Basin

JOHN NORTHROP and ROBERT A. FROSCH

Summary—Recent bathymetric surveys of the North America Basin have shown that numerous seamounts exist off the Northeastern United States' continental shelf as far south as Bermuda and eastward to the foothills of the Mid-Atlantic Ridge. The three seamounts described in this report show typically their conical shape, isolated position, mountainous proportions, 15-20 degree sloping sides and abrupt rise from the flat abyssal plain of the deep-sea floor. The seamounts' location, morphology and association with the Bermuda volcanics indicate that they are extinct volcanoes which probably erupted during the Early Tertiary along lines of weakness set up by previous tangential stresses on the earth's crust.

INTRODUCTION

During the past several years, ships equipped with continuous recording echo sounders have made detailed surveys of portions of the North America Basin and the soundings obtained have been of considerable interest to geomorphologists studying the ocean floor. In the area between Bermuda and Cape Cod, a number of well defined land forms have been described (TOLSTOY, 1951). There are two main geomorphic types present :

1. Destructional land forms such as submarine canyons and slump features.
2. Constructional land forms, such as the flat depositional plains and seamounts.* The latter are of principal interest in this report.

METHOD

The survey ship was equipped with a continuous recording Edo sonic sounder model AN/UQN 1B, modified to record on a scale of 0-600, 600-1,200, 1,200-1,800, 1,800-2,400 and 2,400-3,000 fathoms (NORTHROP, 1953). The instrument was operated continuously on shipboard between New York, Bermuda and return. The courses† chosen for the survey were into those areas where previous sounding tracks are widely spaced and to locations where seahighs were suspected (LUSKIN *et al.* 1952).

OBSERVATIONS

There are many seahighs in the North America Basin (TOLSTOY, 1951 ; FUGLISTER and WORTHINGTON, 1951). A typical example of a seamount was surveyed during a cruise sponsored by Hudson Laboratories' Project MICHAEL. Appropriately named Seamount Michael, this peak is the highest of a cluster of seamounts which rises abruptly from the 2,730 fathom plain. As Fig. 1 shows, Seamount Michael is 18 miles wide and rises to 1,010 fathoms. From a study of the available soundings,

* The term seamount is used in accordance with the definition accepted by the International Committee on the Nomenclature of Ocean Bottom Features, as reported by WISEMAN and OVEY (1953).

† All distances given in this paper are in nautical miles. Depths are based on the standard vertical sounding velocity of 800 fm/sec. and are uncorrected for variations of sound velocity. Loran fixes were taken every fifteen minutes and star positions obtained when possible. The naviagation, where checked by intersecting sounding lines, was found to be good within plus or minus 2 miles.

the feature appears to be a fairly well defined seamount, elliptical in plan, which rises to a double peak shown on the bathogram (Fig. 2). The minimum sounding of 1,010 fathoms gives Seamount Michael a local relief of 1,700 fathoms (10,200 feet). The seamount's sides slope 14°-16° with the horizontal which seems steep for a submarine slope but is in accord with the findings of HESS (1946) and KUENEN (1950) on Pacific seamounts, and the slope on the flanks of other seamounts in the North

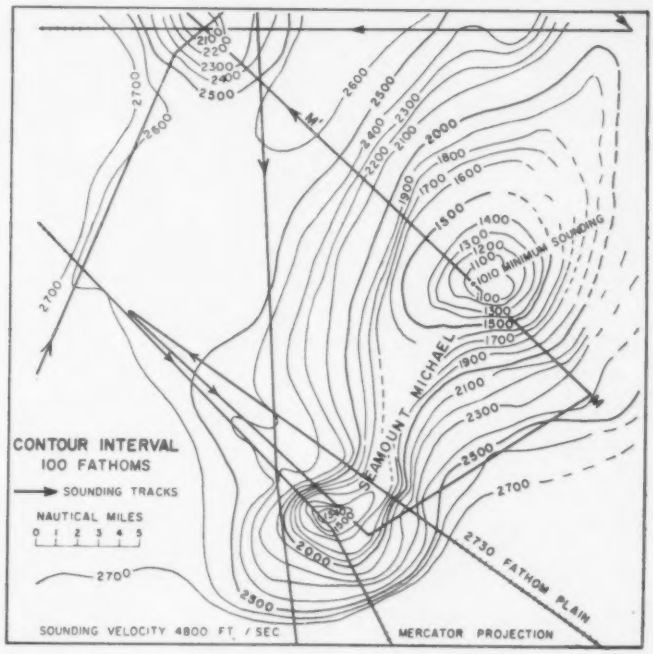

Fig. 1

America Basin. The abrupt angle that the seamount's flanks makes with the sedimentary plain is found on most crossings and is so striking on the bathograms (*M'* of Fig. 2) that the known limit of the plain is represented on Fig. 1 by a series of parallel lines across the sounding tracks that reveal the flat plain.

Detailed sounding tracks 25 miles northeast of Bermuda show (Fig. 3) a 540 fathom seapeak to lie outside the island shelf area. (On H.O. Chart #5723 the 1,000 fathom isobath outlines this seamount). Named Bowditch Seapeak after the USS *Bowditch* which surveyed the Bermuda area in 1940-1941, this seapeak is about 10 miles wide at the base and rises abruptly from the 2,200 fathom isobath on all sides except to the south where it is separated from the Bermudas by the 1,450 fathom isobath and rises " to less than 500 fathoms " (TOLSTOY and EWING, 1949). The bathogram (G-G' of Fig. 2) shows the 540 fathom minimum sounding was obtained over this seapeak's central cone which has sides that slope at 23° down to the 800 fathom isobath. From there, the sides slope 13°-14° down to 1,200 fathoms and then the slope increases to 20°. It is possible that the central peak may be a volcanic cone composed of material similar to the extrusive volcanics underlying the

Paleocene sediment found in Bermuda (OFFICER *et al.* 1952). KUENEN (1950) has pointed out that the towering concave profiles shown by some terrestrial volcanic cones are " most strikingly developed on high cones " and that their concavity is due to erosion rather than collapse. This point is emphasized because submarine volcanoes were found to have sides which slope at a constant rate (KUENEN, 1935) because they are protected from erosion and can maintain their original form. However, a composite volcanic cone built up from the sea floor to and above sea level (KUENEN, 1950) would have a steep sided peak, moderate intermediate slope to the water level, and a steeper base like that of Bowditch Seapeak.

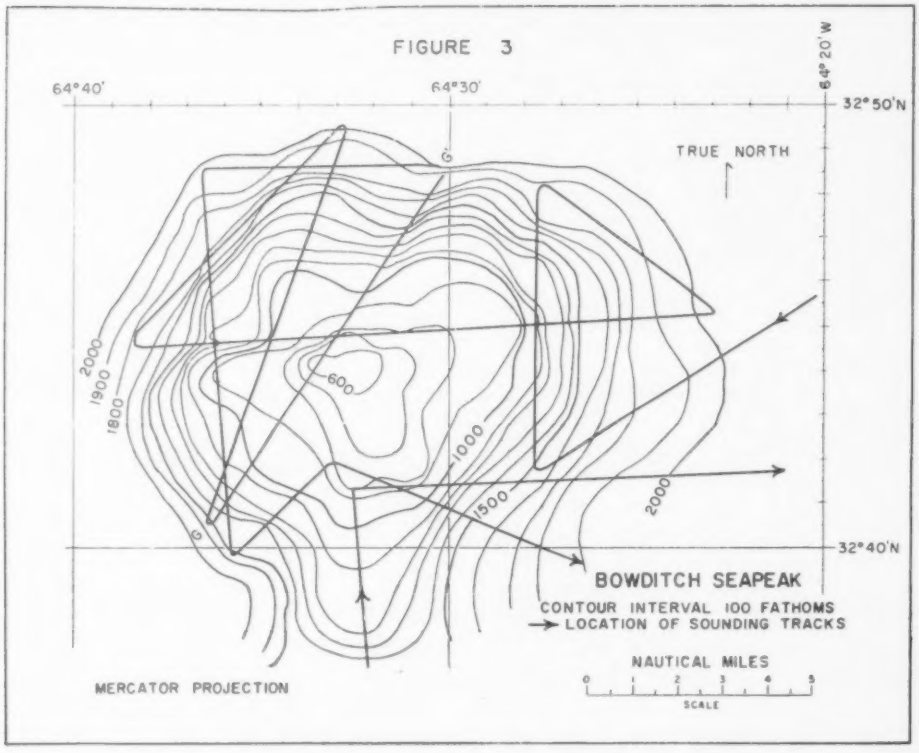

Fig. 3

The analysis of submarine echoes from explosive sound first located reflector G in the vicinity of 33° 22′ North Lat., 60° 48′ West Long. (LUSKIN *et al.*, 1952). Accordingly, the name Seamount George has been attached to the peak which is shown (Fig. 4) to have a base 15 miles wide, sides sloping 14° with the horizontal and a minimum sounding of 1210 fathoms. The seamount actually has twin peaks 2½ miles apart, which, where crossed on the southwesterly traverse (B-B′ of Fig. 5), have minimum soundings of 1340 and 1390 fathoms respectively. The two peaks are separated by a steep walled (25° slope) depression which descends to a depth of 1850 fathoms, but this saddle cannot be delineated further at this time because only one of the traverses in Fig. 4 crossed it.

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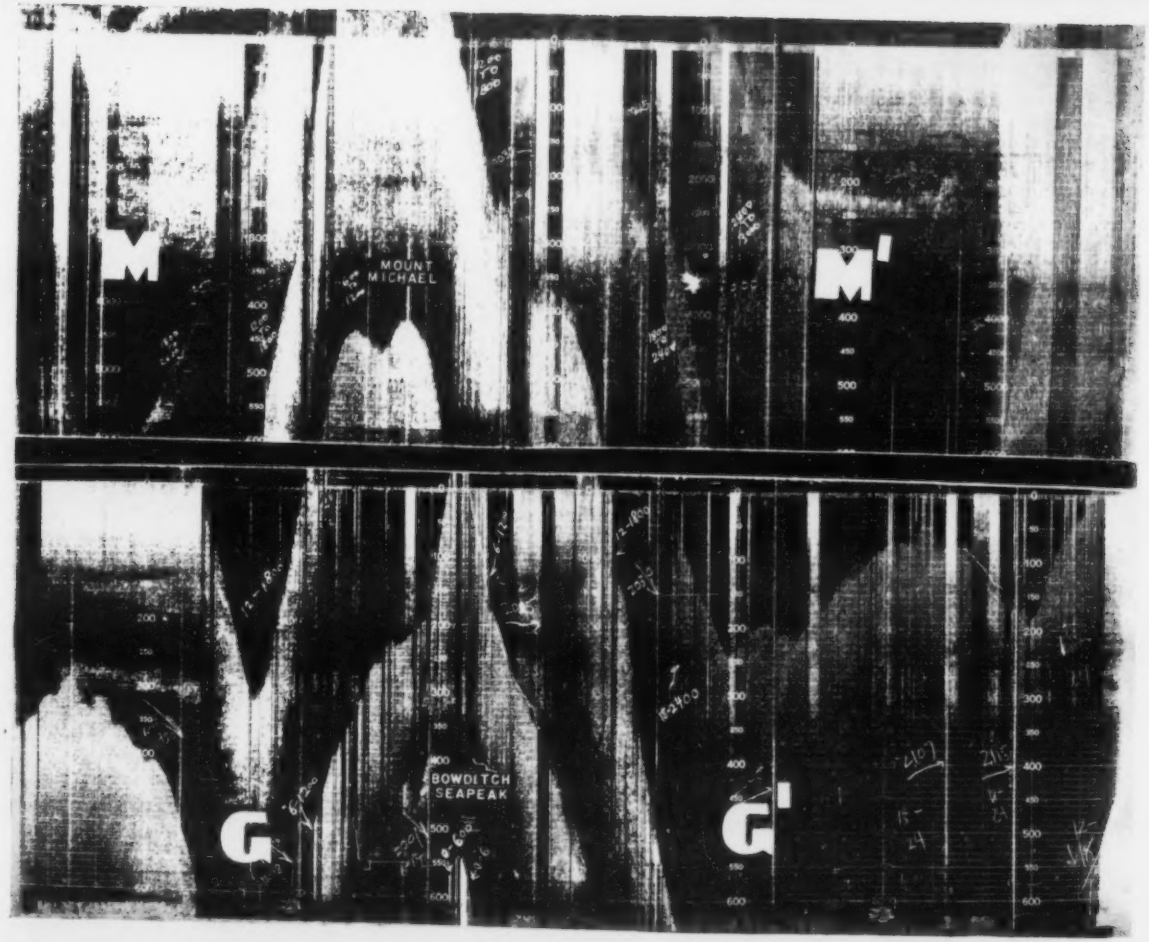

Fig. 2. Bathograms across Seamount Michael (M-M') and Bowditch Seapeak (G-G'). Depths are in fathoms and the horizontal scale is 9/10 of a nautical mile per vertical ruling.

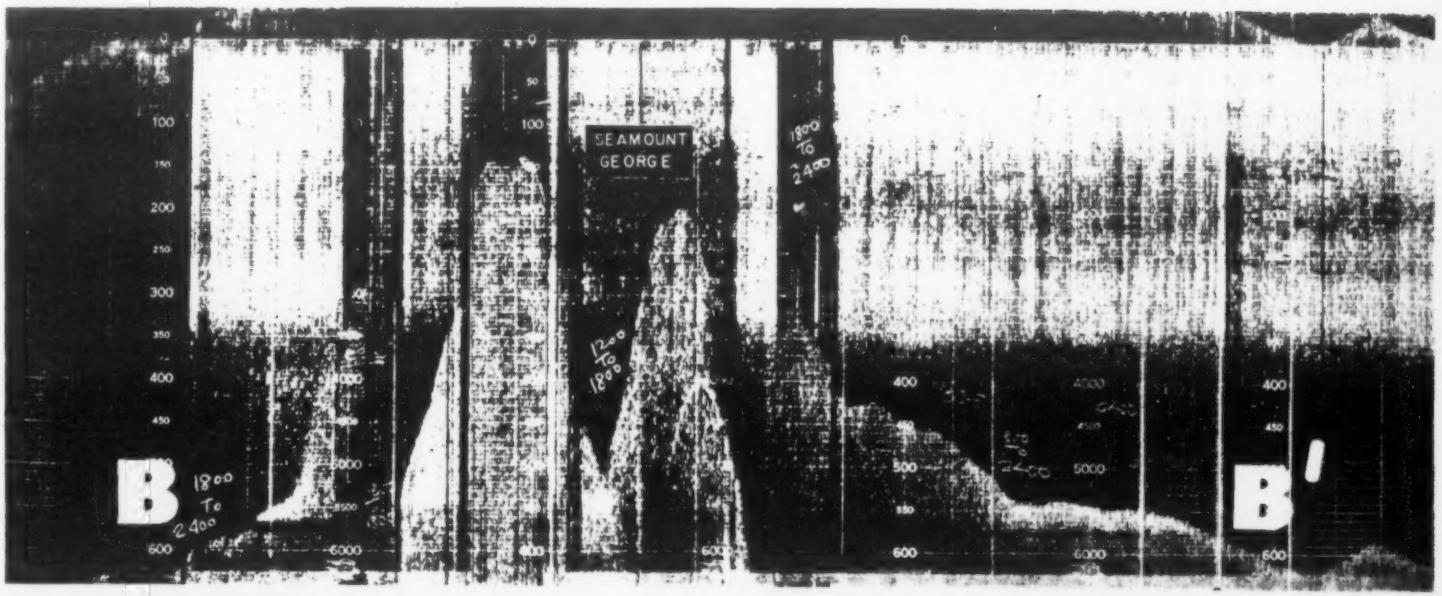

Fig. 5. Bathogram across Seamount George. Depths are in fathoms and the horizontal scale is 9/10 of a nautical mile per vertical ruling.

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Seamount George does not rise from a flat plain, but rather from an undulating ocean floor that varies from 2400-2450 fathoms at irregular intervals. These undulations appear on all sounding lines but with different wave lengths. For instance, on the easterly course they have a wave length of $3\frac{1}{2}$ miles, whereas on a northerly heading across the same area the wave length is 8 miles. This unusual character of the bottom was encountered on other portions of the sounding track within 100 miles of the Bermudas, and is probably due to the sequence of volcanics and sediments found on the Bermuda Rise (OFFICER *et al.*, 1952).

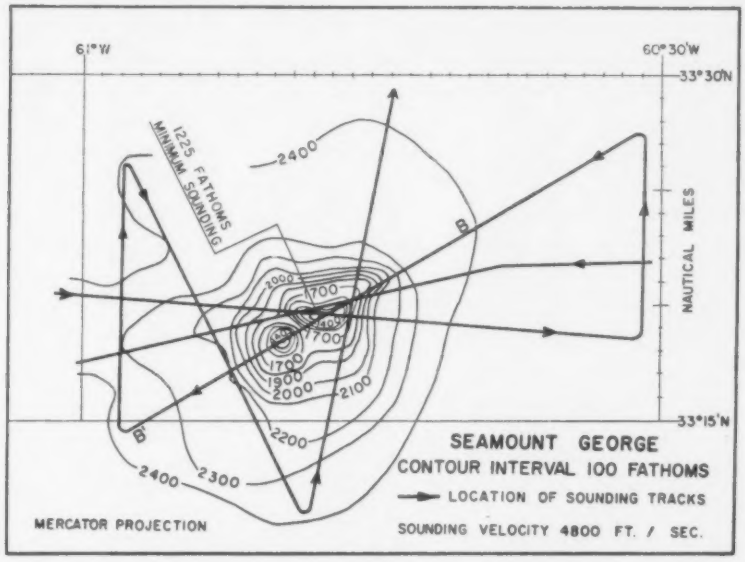

Fig. 4

CONCLUSIONS

The seamounts described in this report are isolated, conical shaped peaks that rise sharply from the sediment covered plains of the North America Basin. The surface of the sedimentary plains meets the 15-20 degree sloping flanks of seamounts at an abrupt angle, and the area between seamounts north of the Bermuda Rise was found to be flat. The flatness of this inter-seamount plain may be due in part to the "masking" of buried topography by sediments, but this process cannot be invoked to explain flat plains covering rough topography, as particles that have come to rest on the ocean floor provide a covering of uniform thickness, except where deposits are concentrated by turbidity current action (LUSKIN *et al.*, 1954).

The existence of flat plains right up to the base of seamounts is one reason why why some seamounts have remained undiscovered in areas where sounding lines are not closely spaced. For example, individual sounding tracks, such as the ones on which this report is based, cover a very limited strip of the ocean bottom. In fact, using the relationship that exists between echo length and the angle subtended by the effective cone of sound (NORTHROP, 1953), the radius of the base of the effective cone of sound, from within which bottom echoes are received at the depths around

Seamount Michael, is in the order of ½ mile. Therefore, a sounding track made but one mile from the base of the seamount would not reveal its presence. Likewise, two surveys covering parallel courses 20 miles apart could straddle a seamount 18 miles wide at the base.

The chain of seamounts discussed in this report appears to be restricted to the area northeast of a line between Bermuda and New York. This alignment of seamounts is significant in discussing their age and origin. In the Pacific, they are found in arcuate patterns associated with and parallel to the arcuate deep-sea troughs accompanying negative gravity anomalies and are thought (HESS, 1948) to be manifestations of the tectogenes that form island arcs. In the North America Basin, however, the seamounts lie in a more linear pattern extending southeast from Cape Cod* and northeast from Bermuda toward the Mid-Atlantic Ridge, without any accompanying deep-sea trench. Their pattern is more like that suggested by SONDER (1939) in his discussion of Lineamenttektonic.

The seamounts' steeply sloping flanks are in accord with the slope found on seamounts in other oceans (KUENEN 1950) and compares with that found on terrestrial basaltic lava cones, steeper than that found on granitic extrusives, but not as steep as that found on either composite or cinder cones. This seems to indicate that the seamounts are basaltic lava cones that have erupted on the ocean floor, the source of lava being the same as that for the sima underlying the ocean basin. The age of these volcano-formed seamounts is unknown, although it is probable that they were formed syngenetically with the upheaval of the welt that forms the Mid-Atlantic Ridge.

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* The Woods Hole Oceanographic Institution has recently surveyed the Northwest part of this chain of seamounts and the results of the survey will presumably be published soon.

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Echograms of the Mid-Pacific Expedition

ROBERT S. DIETZ, HENRY W. MENARD, and EDWIN L. HAMILTON

Summary—About 12,000 nautical miles of echograms (graphically recorded sea floor profiles) were obtained along straight runs between San Diego and the Marshall Islands on the Scripps Institution of Oceanography – U.S. Navy Mid-Pacific Expedition in 1950. This was the first extensive recorded profile ever obtained of the Pacific Basin so that much new topographic information was revealed.

Comparison of the Pacific sea floor profile with others across the United States and the Atlantic reveals the large scale roughness of the Pacific floor, the great size of the seamounts, and the presence of broad low swells.

The Hawaiian Islands are developed on one of these broad swells. Along the northeast side of the Islands there is a deep at the base of Oahu and Hawaii and an arch lying outside. It is believed the deep and the arch are related to crustal yielding in response to the load of the Hawaiian Ridge.

A mountainous region with many guyots was discovered between Hawaii and the Marshall Islands which is termed the "Mid-Pacific Mountains." A Cretaceous reef coral-rudistid fauna was dredged from the mile-deep top of two of the guyots, indicating great drowning.

Exclusive of the Mid-Pacific Mountains, thirty seamounts were crossed, many of which are new discoveries. Fourteen of these are higher than 5,000 feet and six are higher than 10,000 feet. A large guyot with a summit depth of 800 fathoms was discovered north of Midway. Several seamounts appear to have a depressed zone around their bases. Nearly all seamounts probably are of volcanic origin.

Three ridged scraps were crossed, viz., one 150 miles north of Bikini, another 200 miles southeast of Hawaii, and a third, the Mendocino Escarpment, west of California along latitude 40°. These ridged scarps mark abrupt regional changes in sea floor level and probably are formed by faulting.

Three U-shaped depression (grabens ?) were discovered. Two of them, although separated by 1,000 miles, may be developed in the same fracture zone.

Much of the sea floor is rough in topographic detail. This is especially true of the region between the U.S. and Hawaii. Sediment appears to be accumulating largely in the topographic lows forming flat basins over about 37‰ of the track. It seems necessary to assume that there are currents along the deep sea floor competent to erode sediment after it has once been deposited and move it into the lows.

INTRODUCTION

IN July 1950 the Scripps Institution of Oceanography of the University of California and the U.S. Navy Electronics Laboratory embarked on a four month oceanographic expedition to the Mid-Pacific. The vessels participating in this cruise were the research vessel *Horizon* of the Scripps Institution and the USS *EPCE (R)* 857 of the Navy Electronics Laboratory. Approximately, the intinerary of the two ships was from San Diego, California to Honolulu, Hawaii along a V-shaped track reaching almost to the equator ; then westward to Kwajalein and Bikini atolls in the Marshall Islands. The ships returned to San Diego via separate courses. The *Horizon* proceeded via Wake Island, Midway Island, and along the parallel of 40°N whereas the *EPCE (R)* returned via Johnson Island and Oahu. Fig. 1 is a sketch of the tracks of the two ships which together travelled almost 30,000 miles. Fig. 2, 3 and 4 are profiles of the sea floor obtained along the track. Some typical echograms are shown in Plates 1 and 2.

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A study of the bathymetry along the tracks of the vessels was one of about 15 separate scientific programs of the cruise. This was accomplished by the almost continuous operation of the Navy model NMC-2 echo sounder (manufactured by the Submarine Signal Co.) on each vessel which graphically records 17 kc sound pulses reflected from the sea floor. The normal maximum recording range of this echo sounder is 2,000 fathoms but this range was extended by means of a slight modification to the equipment.

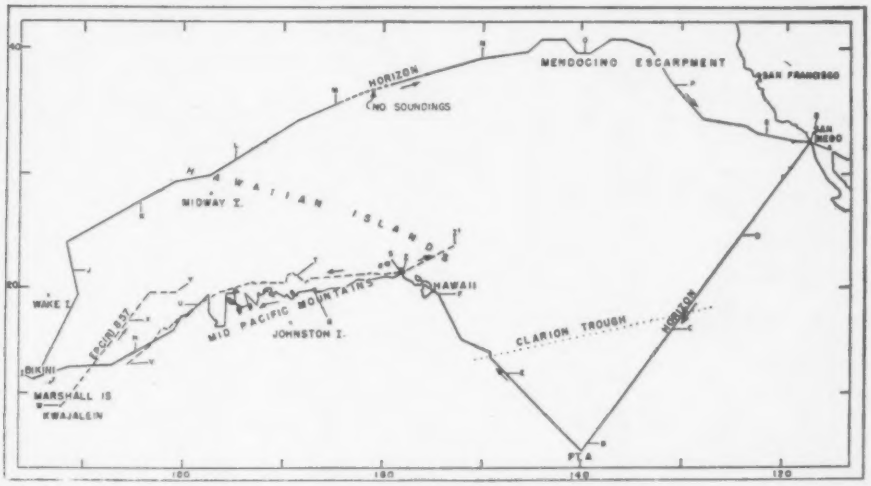

Fig. 1. Track chart showing the course followed by the research vessels *Horizon* and *EPCE* (*R*) 857 on the Mid-Pacific Expedition. The track of the *Horizon* is indicated by a solid line and the locations of sea floor profiles shown in Fig. 2 and 3 are shown by the letters *A* to *R*. The portions of the *EPCE* (*R*) 857 track for which bottom profiles are plotted on Fig. 4 are shown by the dashed line and the letters *T* to *Z*. The General location of the Mid-Pacific Mountains, the Mendocino Escarpment, and the Clarion Trough is also indicated.

Some of the bathymetric results of this Scripps-Navy 1950 Mid-Pacific Expedition have already been reported. MENARD and DIETZ (1952) have described the 1,200 mile-long and 3,000 to 10,000 feet high Mendocino Escarpment discovered along parallel 40°N west of Cape Mendocino, California ; DIETZ and MENARD (1952) have described and attempted to interpret the bathymetry in the vicinity of the Hawaiian Islands ; and HAMILTON (1951a, 1951b, 1953) has described the bathymetry and the fossil pelagic Foraminifera and macrofossils of the Mid-Pacific Mountains which lie completely submerged between the Hawaiian Islands and Wake Island. This paper is a discussion of the over-all bathymetric results with emphasis on those regions not covered in the preceeding papers.

PROFILES ACROSS PACIFIC SEA FLOOR AND NORTH AMERICA COMPARED

In Fig. 5, portions of the section shown in Figs. 2 and 3 are compressed to a vertical exaggeration of 100 so that they can be directly compared with profiles prepared by SHEPARD (1948, Fig. 94) across the United States and across the South Atlantic. This comparison emphasizes the great distance traversed on the Mid-Pacific Expedition and relates the scale of sea floor relief to well known physiographic features.

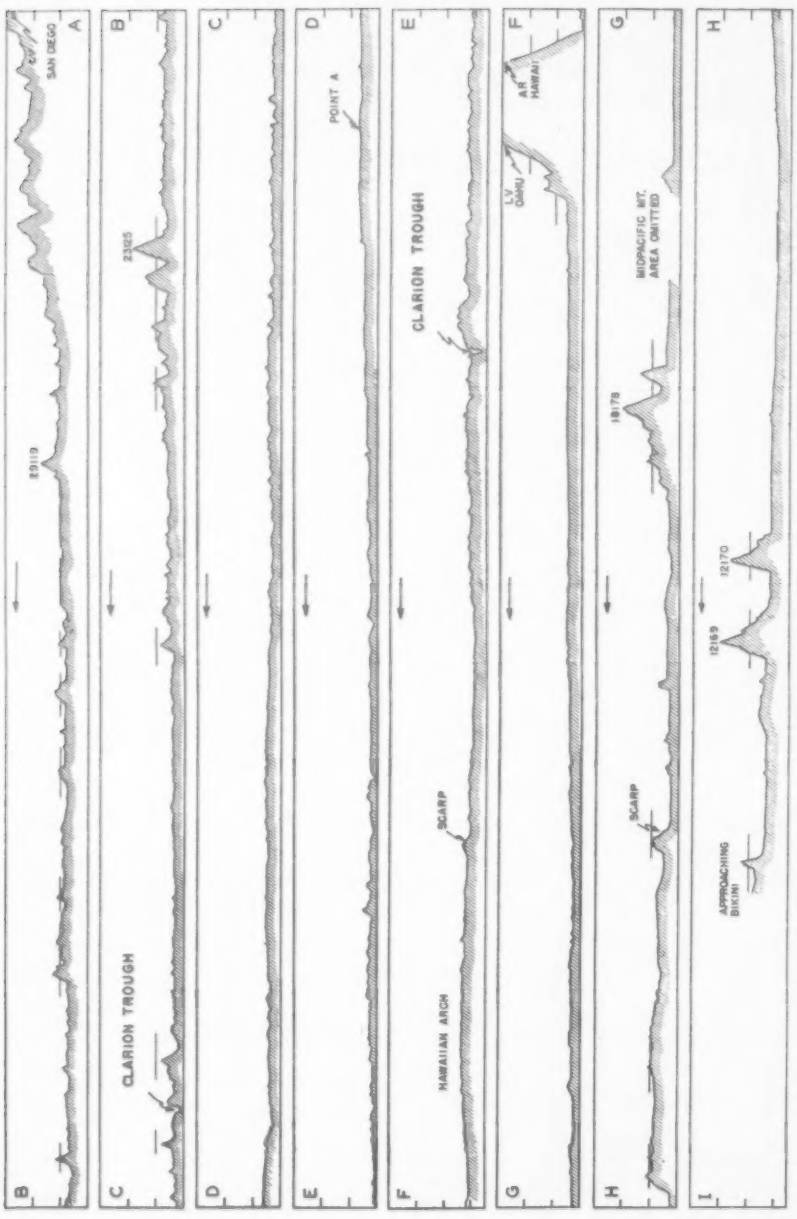

Fig. 2. Sea floor profile obtained by the *Horizon* on the Mid-Pacific Expedition on the outgoing passage from San Diego to the Marshall Islands. See Fig. 1 for the location of the profiles. Dashed portions of the bottom show where the echogram was difficult to read with certainty. Depth is shown by the indices at the right and left margins which mark 1,000 fathom intervals. The arrows indicate the direction of ship travel. Many of the seamounts are indentified by a number, the first two digits giving the location in latitude and the last three giving the longitude to the nearest degree. The profile is shown with a vertical exaggeration of 12 times.

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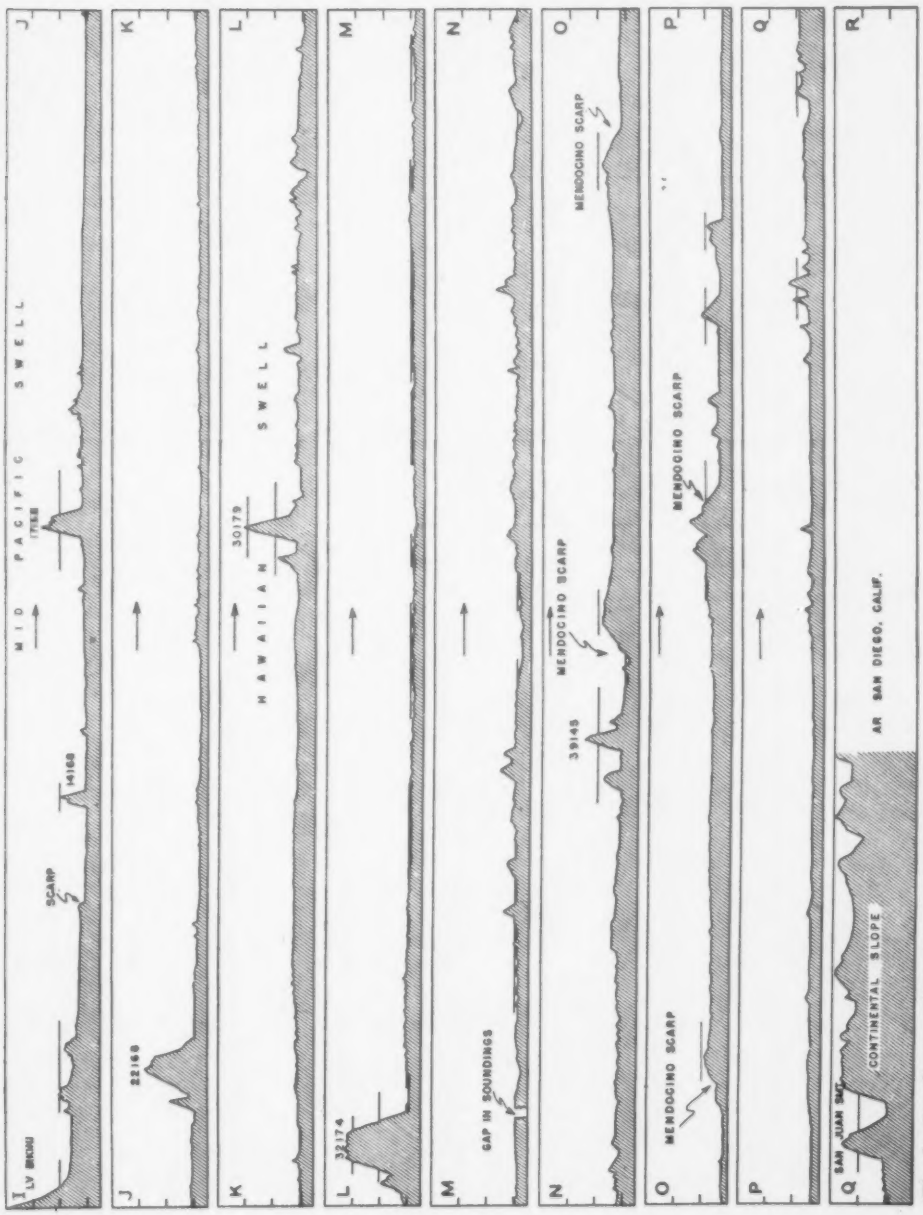

Fig. 3. Sea floor profiles obtained by the *Horizon* on the return passage from Bikini to San Diego showing the Mid-Pacific Swell, the Hawaiian Swell, and four crossings of the Mendocino Escarpment. The track for this profile is shown in Fig. 1. See caption to Fig. 2 for detailed explanation of the showing of the profile.

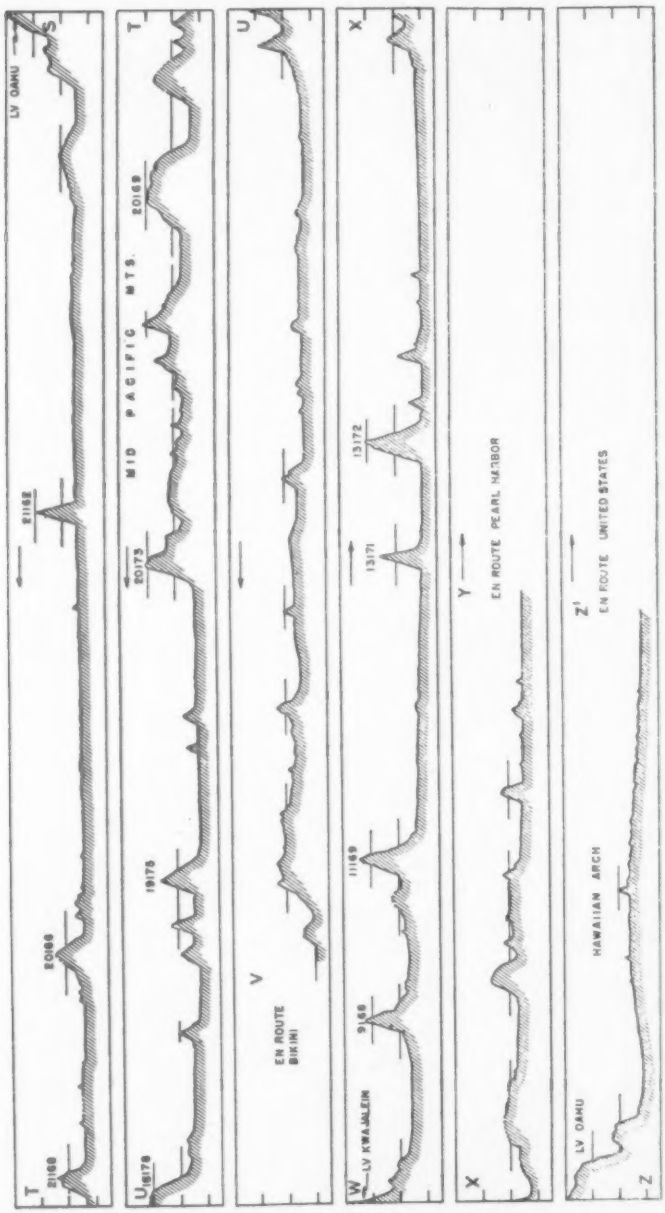

Fig. 4. Sea floor profiles obtained by the *EPCE (R)* 857 on the Mid-Pacific Expedition, 1950, for the region from Oahu to Bikini, from Kwajalein toward Oahu, and from Oahu across the Hawaiian Swell toward the U.S. See the caption to Fig. 2 for details of the method of drawing and see Fig. 1 for the location of the track.

Perhaps the most striking aspect is the size and the great height of Hawaii. Mauna Kea (elev. 13,784 ft.) lies only 39 nautical miles southwest of a sounding of 3,040 fms giving a relief of 32,024 ft. over this short distance. According to H.O. chart 5653, the deepest sounding in the Hawaiian Deep is 3,280 fms so that the total relief from this point is 33,505 making Hawaii by far the highest mountain in the world.

The profile also emphasizes the Mid-Pacific Swell and the Hawaiian Swell from which high seamounts rise comparable to and, in some instances, even higher than the Sierra Nevada. None of the swells, however, have the vertical relief of the elevated region of the western United States or of the Mid-Atlantic Ridge. It can also be seen that no stretch of the sea floor is as smooth, on this scale, as the region extending from the Great Plains to the Appalachian Mountains.

The large scale of the Mendocino Escarpment is also apparent by comparing it to the Appalachian Mountains, for example, which on this scale are a minor feature. The Mendocino Escarpment varies from ½ to 2 miles high and extends at least for a distance equivalent to that from New York to Denver.

HAWAIIAN REGION

During the Mid-Pacific Expedition, profiles were obtained of the sea floor structure around the Hawaiian Islands in the vicinity of Oahu, Hawaii, and Midway (Fig. 1). A study of these Hawaiian structures has already been published (DIETZ and MENARD, 1953) so that only a brief summary need be given here.

The fundamental structure of the Hawaiian region appears to be a long, low and broad rise in the sea floor, the Hawaiian Swell or Rise which is about 3,000 feet high, 600 miles across, and 2,000 miles long, extending from near Hawaii Island to far beyond Midway Island. A long narrow and high ridge, the Hawaiian Ridge, is superimposed on the swell, and the Hawaiian Islands are, of course, merely the above water portion of this ridge. A depressed zone, deep, or " moat " is present along the north-east side of Oahu and along the northeast and hooking around to the south side of Hawaii.

Seaward of the depressed zone, the sea floor is arched up over a distance of more than 200 miles. The two crossings across the arch made 10 miles apart southeast of Hawaii, show an abrupt ridged escarpment marking the outer limit of the arch (Plate 1, Profile C) which almost certainly was formed by a fault. However, east of Oahu, the outer limb of the arch gradually merges with the deep sea floor and no fault is present (Fig. 4, Profile Z-Z'). Along the inner limb of the arch the sea floor is smooth but along the outer limb the bottom is rough. More recent information shows that this contact between smooth and rough bottom marks the beginning of the Baja California Seamount Province (MENARD, in press), a major geomorphic province in the northeast Pacific. This province, which extends from the top of the Hawaiian Arch to the base of the continental slope off southern California and Baja California, is characterized mainly by bottom with roughness of moderate amplitude and with many large seamounts.

It is considered that the Hawaiian structure is related to vertical forces which have arched up the crust and produced tension fractures out of which lava has poured. Arching of the sea floor above the zone of divergence in two thermal convection cells in the earth's mantle might account for the Hawaiian Swell. Deep

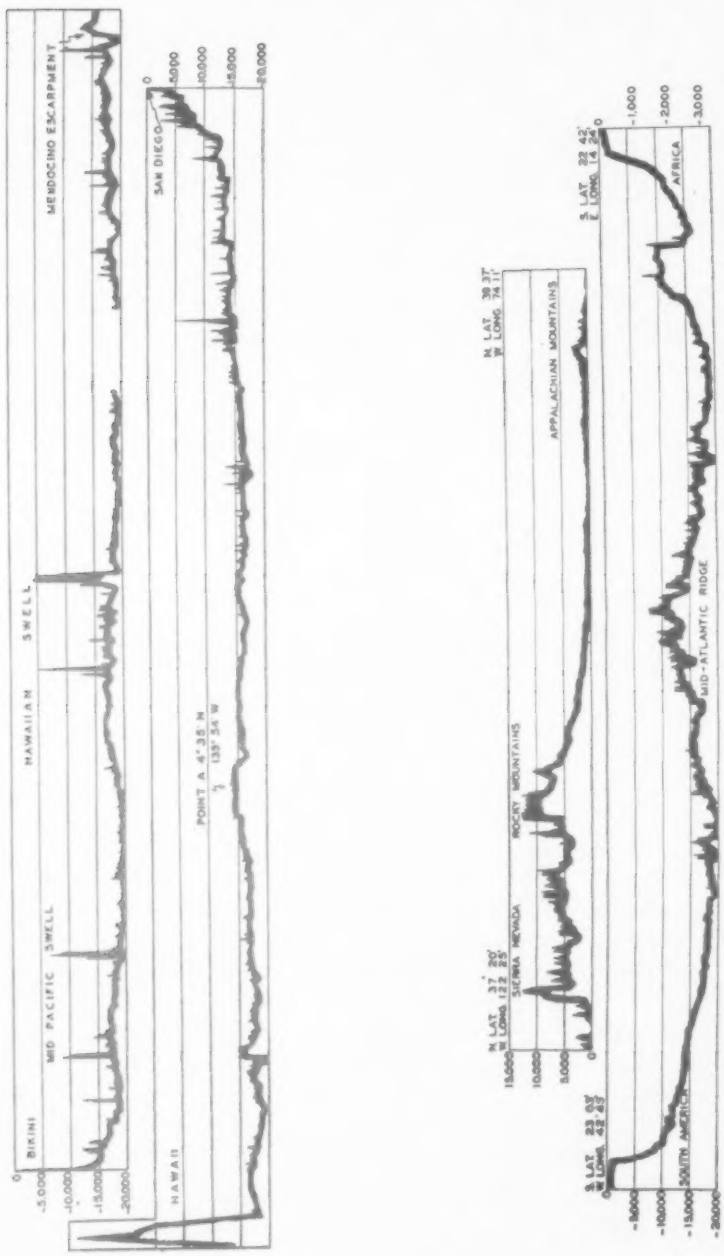

Fig. 5. Compressed profiles of portions of the bottom of the Pacific from the Mid-Pacific Expedition compared to profiles (from SHEPARD, 1948, p. 282, fig. 94) across the United States from Geological Survey topographic sheets and across the South Atlantic from *Meteor* soundings. Vertical exaggeration is 100 times. Elevations and depths are marked in feet.

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terraces at depths as much as 700 fathoms around the Hawaiian Islands appear to be drowned shelves and suggest that the Hawaiian Islands have isostatically subsided, owing to overloading of the crust. Further evidence is provided by the moat and the Hawaiian Arch as they also may be caused by a regional yielding of a semi-rigid crust. The presumed fault present at the outer edge of the arch off Hawaii may have been formed by failure of the crust to this stress imposed by the Hawaiian Ridge. Here, as in the region of the arch, the stress is directed upward.

MID-PACIFIC MOUNTAINS

A special exploration was made of a mountainous area between the Hawaiian Islands and Wake Island because existing sounding showed the presence of a number of flat-topped seamounts of the type which have been termed "tablemounts" or "guyots" (HESS, 1946). About 2,000 nautical miles of soundings were recorded

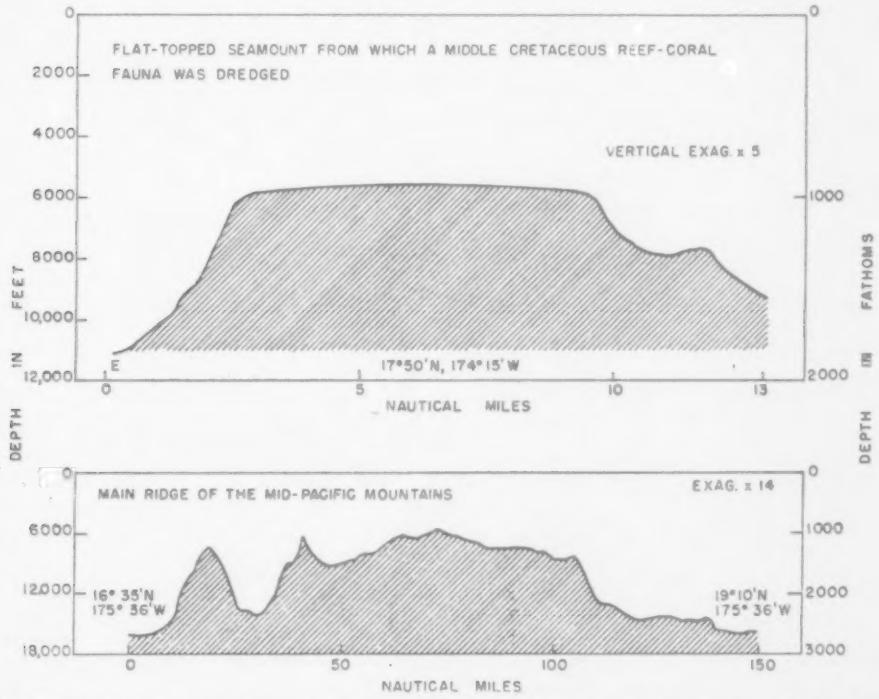

Fig. 6. Top: A profile of one of the guyots (Hess Guyot) in the Mid-Pacific Mountains from which a Cretaceous reef coral rudistid fauna was dredged. Note that flat top and the abrupt break-in-slope at the edge of the summit. Bottom: A profile across the main ridge of the Mid-Pacific Mountains.

in this region between 167° and 169°W Long. and 16° and 20°N Lat. by the *Horizon* and by the USS *EPCE* (*R*) 857. The results of this work have been reported in detail by HAMILTON (1951a, 1951b, 1953, in press) so that they will be only briefly summarized here. Inasmuch as there was complicated maneuvering through this region, the bottom profiles are not shown on Fig. 2 but a small section is shown in Fig. 4.

The soundings from the expedition plus earlier soundings revealed the presence

of a rugged and topographically high region extending from Necker Island in the Hawaiian Islands to the vicinity of 170°E Long., a distance of about 1,450 nautical miles (Profiles A and B, Plate 1). The name " Mid-Pacific Mountains " was adopted for this east-west structure. Near Necker Island the structure is only 25 miles wide but it reaches a maximum width of 600 miles between 180° and 175°E Long. Structurally the Mid-Pacific Mountains appear to be a low, broad east-west swell in the sea floor upon which are superposed numerous large volcanic seamounts many of which are flat-topped. Fig. 6 (top) shows a profile across one of these guyots. Linear trends in some places indicate that faulting may have been of some importance in the formation of this mountain range. A study of U.S. Navy Hydrographic Office soundings shows that this zone of shallow topography and numerous seamounts commences again at Wake Island and continues at least to Marcus Island. This may be an extension of the Mid-Pacific Mountains structure because the passage of the *Horizon* through the saddle region when returning to San Diego (Fig. 3 Profile I-J and Fig. 5, top) revealed a broad, low swell.

Five flat-topped seamounts of the main range were cored and dredged. Four of these were indicated by existing soundings ; the fifth was a new discovery. These guyots have flat tops between 700 and 900 fathoms and the side slopes are concave upward with a maximum slope of about 20 degrees near the top. They are symmetrical in profiles and oval in plans with the exception of one which is a flat-topped ridge. All of the five seamounts have perceptible breaks-in-slope between the upper

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PLATE 1. (*right*) MID-PACIFIC EXPEDITION ECHOGRAMS SHOWING TROUGHS, SCARPS, AND A MID-PACIFIC MOUNTAIN PROFILE.

All soundings are on deep scale so that the depth in fathoms indicated on the printed scale must be multiplied by five. In addition, all profiles, except the tops of seamounts which jut far above the usual level of the bottom, are on the 2,000 fms-plus scale so that 2,000 fms must also be added. Thus a depth reading of 190 ordinarily equals 190 × 5 plus 2,000 or 2,950 fms. Those portions of the echogram which are shoaler than 2,000 fms are indicated with ruled lines. The standard underway speed of the ships was 12 knots. The printed ordinates on the echogram represents twenty minute intervals so that three of these equals one hour or a distance of 12 nautical miles. The vertical exaggeration of the profiles is, therefore, about 25 times. The recording stylus of the NMC-2 echo sounder rotates in a circle so that the profile is not rectilinear but rather arcuate. The depths of the echograms are uncorrected and are based on the standard sounding speed of 4,800 ft./sec. Thus, the sea floor is in all cases deeper than indicated by about 2 per cent up to 1,800 fms and by about 3 per cent at 3,000 fms.

(A) A profile across a section of the Mid-Pacific Mountains showing the mountainous topography of the region. The eastermost seamount (right hand side of the echogram) has a minimum depth of 970 fms and has a beveled top so that it is a guyot. In the center of the profile there is a perched basin, higher than those flanking the range to the east and west.

(B) A continuation of profile " A " to the west (left).

(C) Ridged scarp marking a regional change of 160 fms in the level of the sea floor and marking the beginning of the Hawaiian Arch 200 miles southeast of Hawaii Island. Northwest is to the right. Regional location shown on Profile E-F of Fig. 2.

(D) A ridged scarp, with an essentially vertical face of 250 fms relief, which marks a regional change in sea floor level separating the rise on which the Marshall Islands are developed from a deeper portion of the Pacific floor to the northeast. The bottom here is smooth. This profile is also drawn on Profile I-J of Fig. 3. Seamount 14,168 is shown near the east (right) end of the section.

(E) Echogram of the sea floor showing the eastern crossing of " Clarion Trough " which reaches a depth of 2,900 fms. This section is also shown in Profile B-C of Fig. 2.

(F) West crossing of " Clarion Trough " in the Clarion fracture zone. The maximum depth is 3,320 fathoms uncorrected (i.e. about 3,430 fms true depth) which is the greatest depth encountered on the Mid-Pacific Expedition. This profile is also shown on Profile E-F of Fig. 2.

(G) The irregular crest of the Hawaiian Swell is displayed in this profile. Note the large trough which descends to 3,150 fms. This trough is about 5 miles across and is 300 fms deeper than the regional level of the floor. This profile is also shown on Profile K-L of Fig. 3.

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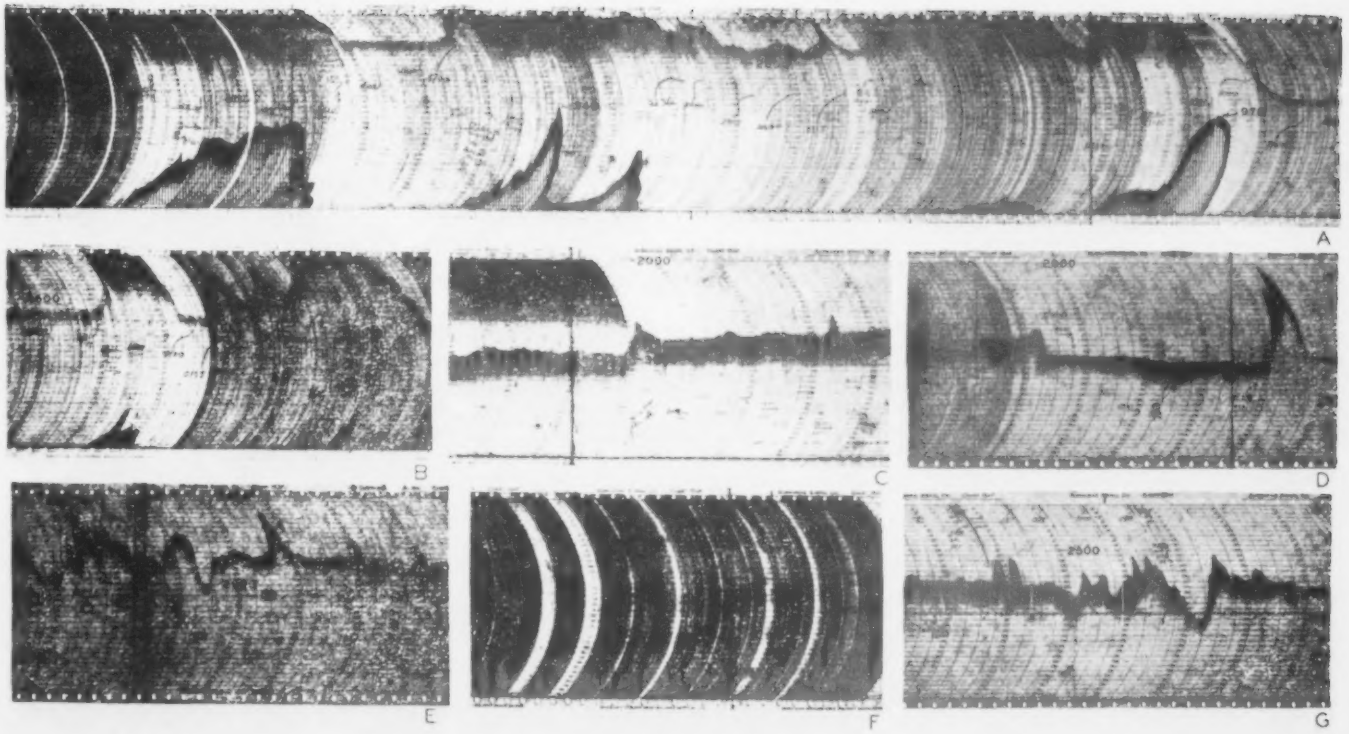

PLATE 1.

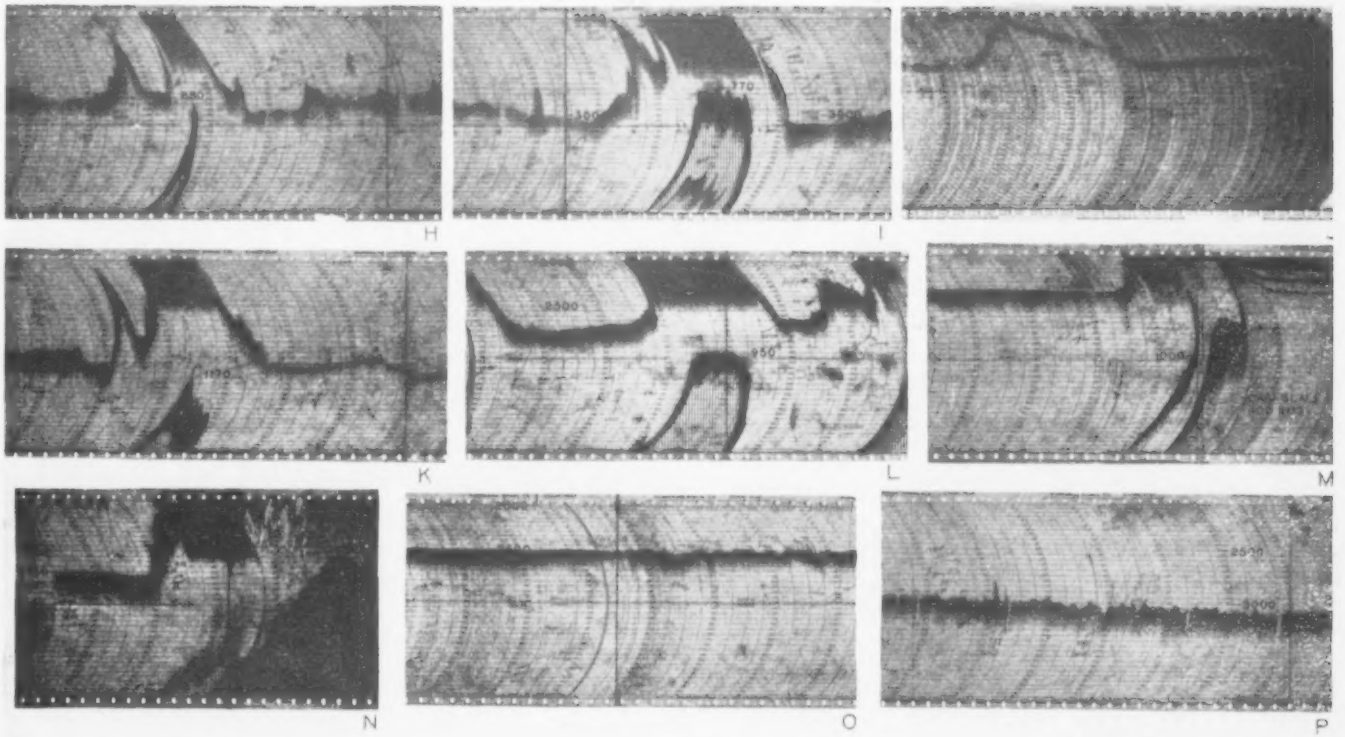

PLATE 2.

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side slope and the flat tops. Within the range of summit heights, there do not seem to be any preferred levels. The data are too few to allow other than a random distribution of heights to be assumed.

In accordance with the plan of the expedition, the dredging was done largely at the margins of the flat tops of the guyots in an attempt to recover fossil remains of shallow water organisms. It was believed that the guyots might possibly be deeply drowned coral reefs. This belief was confirmed by the recovery from two seamounts of a well-integrated fossil fauna of reef coral, rudistids, stromatoporoids, gastropods, pelecypods, and an echnoid. At both localities, the age of the assemblage is Cretaceous (Aptian to Cenomanian) with affinities for the faunas of the Tethyan Province. Fig. 6 (top) shows the seamount from which the major portion of the fossil reef coral assemblage was dredged. In each case, volcanic rock was recovered in the same haul or in a nearby haul so that these guyots appear not to be drowned atolls but, instead, drowned basaltic platforms on which some reefs grew.

The tops of the guyots are covered with globigerina ooze, basaltic detritus, and bedrock. Rounded sand grains, pebble, cobbles, boulders of olivine basalt, and sand-

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PLATE 2. (*left*) MID-PACIFIC EXPEDITION ECHOGRAMS SHOWING SEAMOUNTS AND OTHER FEATURES ENCOUNTERED IN THE NORTH PACIFIC OCEAN.

For method of reading the echogram refer to explanation for Plate 1.

(H) A profile across the Hawaiian Swell showing the irregular form of the bottom and showing Seamount 30,179 rising to 890 fms. The pointed form of the feature indicates that it has been "sideswipe," i.e. the profile goes over the flank of the seamount and not over the summit. This profile is also shown on Profile K-L of Fig. 3.

(I) Seamount 32,174, which rises from 3,080 fms to 770 fms, has a total relief of 13,860 feet. This seamount appears to have a truncated summit suggesting that it is a guyot even though the summit topography is rough. The sea floor on both sides of the seamount is depressed below the regional level suggesting that an annular depression or "moat" may be present. This profile is also shown on Profile L-M of Fig. 3.

(J) A unique asymmetric feature encountered on the Mid-Pacific Expedition immediately west of Oahu. This asymmetrical block rises 600 fms from a regional depth of 2,500 fms. The bottom is level to the east at the base of Oahu but slopes to the west. This slope appears to be a flank of a poorly developed arch on the southwest side of the Hawaiian Islands.

(K) Seamount 22168 encountered on the return passage from Bikini to the U.S. It lies between the Mid-Pacific Swell and the Hawaiian Swell. If the summit was crossed, this seamount has an irregular top and hence is a seapeak rather than a guyot or tablemount. This profile is also shown on Profile J-K of Fig. 3.

(L) A large-flat-topped seamount or guyot in the Mid-Pacific Mountains is shown in this profile. It rises from 2,700 fms to 950 fms which is typical of the summit depth of the guyots of this region. Note the abrupt break-in-slope at 1,050 fms on the west (left) side and the bevelled slope rising to the summit. If a profile of the seamount were drawn without the 25 times vertical exaggeration, the flatness of the top would be more apparent.

(M) Echogram showing the flank of Bikini Atoll. The sea floor is about 2,400 fms deep and it descends slightly toward the base of the Atoll. The side rises abruptly to 1,000 fms where the slope becomes even steeper possibly marking the contact between the volcanic seamount and coral talus. At 400 fms the echo sounder was switched to shoal scale (0-400 fms for the width of the paper) so that a blown up view of the top 400 fathoms is presented. In this portion of the echogram, a profile through a pass in the reef and into the lagoon which has a depth of 27 fms is shown. The level stretch near the top of the atoll is caused by the ship running parallel to the contours for several minutes. The long echo extension shows that the bottom is actually steep.

(N) This profile shows smooth sea floor abutting against the base of a seamount in the Mid-Pacific. It is especially noteworthy that the sea floor is bent down as the seamount is approached, suggesting that the bottom has yielded to the load of the seamount.

(O) A profile between Oahu and the Mid-Pacific Mountains showing the contact between rough and smooth bottom at 2,500 fms. Between the large seamounts, such smooth bottom was characteristic of the track between Hawaii and the Marshalls. Rough bottom characterized the track east of Hawaii. The stretch of sea floor is shown in the middle of Profile G-H of Fig. 2.

(P) A 120-mile stretch of the sea floor on the eastern flank of the Hawaiian Swell east of Midway which deepens to east (left). Minor roughness, with an amplitude of about 50 fms, characterizes this flank of the Hawaiian Swell. This profile is redrawn as the middle portion of Profile L-M of Fig. 3.

stone with minerals derived from basalt were recovered. The lithology is similar to that of the Hawaiian Islands. Some of the cobbles were too well rounded to have formed in their present enviromennt. They appear to have been rounded under conditions of vigorous current action such as is found in the surf zone.

A study of the globigerina ooze from the Mid-Pacific Mountains (HAMILTON, 1953) has revealed the presence of an extensive pelagic fossil fauna. Foraminifera of Cretaceous (Campanian-Maestrichtian), Paleocene, Eocene, Oligocene, Miocene, and Recent age have been identified. The fauna is in an excellent state of preservation without evidence of corrasion or solution.

The writers interpret the geologic history of the Mid-Pacific Mountains as follow: A broad swell formed in the sea floor at some time prior to the Middle Cretaceous. This arching of the sea floor may have formed above the divergence of two thermal convection cells in the earth's mantle. Tensional fissures developed in the arch out of which lava poured forming numerous large volcanos. Some of the larger of these volcanos pierced the surface of the ocean and thus became islands. It is believed that extensive horizontal buckling of the crust such as has formed the folded alpine mountains on the continents has not taken place here. This sequence is similar to that proposed by DIETZ and MENARD (1953) for the Hawaiian Islands. These islands were then truncated by subaerial erosion and wave action and Cretaceous coral reefs grew on the shelves around these islands. Subsequently the islands began to sink. Some unfavourable ecological conditions or rapid initial sinking prevented the coral reefs from keeping pace with the subsidence of the banks so that the reefs were killed. Subsequently subsidence continued to the present depth of the guyots of about 1 mile. The writers consider the drowning to be largely the result of regional yielding of the earth's crust to the load of the Mid-Pacific Mountains and local yielding to the load of the particular guyot rather than an absolute rise of sea or to some other cause.

The macro-fossils from the Mid-Pacific Mountains are the oldest yet recovered from the Pacific Basin. Assuming that guyot summits are structurally undeformed so that the reefs are in their original position except for submergence, they give evidence that the Pacific Basin is at least as old as Aptian-Cenomanian. They also show that the Pacific Basin was a deep sea basin in the Cretaceous, because, although they are one mile below present sea level, they are two miles higher than the general level of the sea floor. The supposition of HESS (1946) that the summits of the guyots subsided below sea level in pre-coral reef time (Pre-Cambrian) is disproved.

SEAMOUNTS

Exclusive of the Mid-Pacific Mountains where numerous seamounts were found, thirty seamounts were crossed, many of which are new discoveries. (Seamounts are defined as isolated rises with more than 500 fathoms relief, i.e. 3,000 ft. or about 1,000 m and isolated rises smaller than this are termed seahills or seaknolls). Fourteen of the seamounts have crossings which are higher than 5,000 ft. and 6 are higher than 10,000 ft. Surveys were not made so that the minimum depths are not known.

Several guyots were discovered in the Mid-Pacific Mountains (HAMILTON, 1951b ; in press) and Sylvania Guyot near Bikini Atoll was surveyed and sampled in considerable detail. The bathymetry and sediments from Sylvania Guyot are discussed by EMERY, TRACEY and LADD (in press) and the volcanic rocks which were dredged are

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discussed by MACDONALD (in press). Otherwise, only one guyot, Seamount 32174, was found. (Profile L-M of Fig. 3 and Plate 2, I). However, some of the other seamount profiles are almost certainly flank crossings which did not pass over the summit. Future detailed surveys of these may show that some are guyots.

Irregular depressed profiles were found at the base of three large seamounts (30179, 32174, and 21162). At the base of three others (21162, Bikini Atoll, and a seamount in the Mid-Pacific Mountains) the sea floor is smoothly downbowed. The last two named are figured in Plate 2, M and N. Judging from the Hawaiian Islands, which were discussed earlier, it appears likely that these profiles are across depressed zones or " moats " which extend around these seamounts. It seems probable that such saucer shaped depressions are formed by semi-rigid yielding of the crust to the load of the seamounts. However, the possibility cannot be eliminated that they are caused by foundering following the extraction of magma during the formation of a volcanic seamount.

Volcanic rocks were dredged from five seamounts in the Mid-Pacific Mountains and from Sylvania Guyot, bearing out the probable volcanic nature of most seamounts which is apparent from their conical shape. One seamount (Plate 2, J), however, has an asymmetrical form, suggesting that it is a fault block.

RIDGED SCARPS

Along the track of the Mid-Pacific cruise three large escarpments were crossed. These are not simply a step-like displacement of the sea floor but rather are a step-like displacement upon which is superposed an asymmetrical ridge. Thus, they can be termed " ridged scarps." Profiles of two of these are shown in Plate 1 (Profiles C and D). The first was encountered at lat. 16° 20′N, long. 153° 00′W, about 220 miles southeast of Hawaii. The second was found at lat. 14°00′N and long. 166°40′E, 150 miles northeast of Bikini. The third is the Mendocino Escarpment, located along latitude 40°N and extending west of Cape Mendocino. This enormous escarpment is from 3,500 to 10,000 ft. high and more than 1,200 miles long. It is the subject of a separate paper by MENARD and DIETZ (1952) to which the reader is referred for a detailed description.

In all these scarps there is a regional difference in level of the earth's crust between the two sides. The Hawaiian and the Marshall Island scarps separate a regional change in level of about 1,000 ft. whereas the Mendocino Escarpment separates a regional change of about 3,000 ft.

The scarp face may be quite steep. Assuming that the sound cone had a half-angle of 30°, the Marshall scarp, for example, is essentially vertical for over 1,000 ft. The Mendocino Escarpment averages 10° and has maximum slopes of about 30°. The presumably volcanic slopes of seamounts are generally about 10° but sometimes are as much as 22°. Slopes greater than this strongly suggest faulting.

The ridged scarps may have considerable linear extent. The Mendocino Escarpment is known to be more than 1,200 miles long. The Hawaiian scarp was crossed on two tracks ten miles apart. Only one crossing was obtained of the Marshall scarp so its linear development is not known.

The steepness, the linear extent, and the regional difference in level of the sea floor all suggest that these scarps are fault scarps marking major fractures in the earth's crust. A possible mode of origin of the Hawaiian scarp already has been

discussed. The crustal blocks bounded by the Mendocino Escarpment are of large size so that they must be presumed to be in isostatic equilibrium. Thus the higher level of the north block as compared to the south block may reflect a change in rock density. The scarp, with its complex structure, may have formed along the transition zone between two regions of different crustal composition.

By using recent soundings, MENARD (in press) has found that the Mendocino Escarpment is one of four sub-parallel fracture zones that extend in a roughly E-W direction, following the arcs of a great circle, in the northeast Pacific Ocean. The "Clarion" Trough, discovered on the Mid-Pacific Expedition, forms part of one of these zones.

U-SHAPED DEPRESSIONS

Three large U-shaped depressions were found along the tracks of the vessels on the Expedition. The echograms of these are reproduced in Plate 1, E, F, and G. One U-shaped depression was encountered along the crest of the Hawaiian Swell north of Midway. Two others were discovered east of Hawaii. Although these are 1,000 miles apart, MENARD (in press) has shown that they probably occur in different parts of a long fracture zone in the northeast Pacific which he has termed the "Clarion Fracture Zone." It is believed that many troughs are discontinuously present along this zone.

It is supposed that these troughs are large grabens. They are topographically quite different from the trenches or foredeeps associated with island arcs.

SMALLER TOPOGRAPHIC FORMS

In this paper, smaller topographic forms include all the features which have less relief than seamounts and which are not identifiable as esca pments, swells, etc. The echo sounders used scan an area of the bottom with a diameter of about one half times the depth ; thus these instruments are not able to resolve features on the deep-sea floor which would be termed minor relief on land. Small valleys and depressions would have been completely missed.

The sea floor along the track between California and Hawaii is notable for its minor irregularities which yield a jagged trace on the fathogram (Profiles A-F of Fig. 2). Off Baja California, no areas of flat bottom were crossed for hundreds of miles, although the side slopes of many topographic features are no greater than 1½ degrees. Representative features are two to four miles wide and from 300 to 1,800 ft. high. Between 17°N latitude and Point A, the smaller topographic features are more subdued, more rounded, and less symmetrical in profile than those off Baja California. Representative features are three to nine miles wide and 300 to 1,200 ft. high.

Another area displaying minor irregularities rather than smooth bottom or major topography was crossed between the Hawaiian Swell and the Mendocino Escarpment (Profiles L-M and M-N of Fig. 3). The individual features are roughly two to four miles wide and 300 to 1,200 ft. high.

The origin or origins of the smaller topographic forms cannot be determined from the MidPac fathograms. Numerous minor jogs in course were made over these rough areas, as elsewhere, in order to take routine measurements of surface currents. Consequently, the relief in three dimensions can be established for very limited

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areas a few miles on a side. These " surveys " suggest that most of the features are hill-like, i.e. equidimensional rather than linear, although the side slopes are very gentle.

The great depth of the " hills " appears to obviate any possibility of a subaerial erosional origin. Nor does differential deposition of sediment or submarine erosion seem a plausible explanation for topographic highs. By elimination, the " hills " must be produced by vulcanism or folding and faulting. Some of the higher features with steeper slopes undoubtedly are the flanks of major seamounts. The more asymmetrical features may be fault blocks particularly between Hawaii and the Mendocino Escarpment where most of the track appears to lie near a major fracture zone which extends west from the Mendocino Escarpment. The " hills " off Baja California may be very low volcanic cones or fissure lava flows.

BASINS OF SEDIMENTARY ACCUMULATION

By visual inspection of the bottom profiles, an estimate was made of the percentage of smooth or nearly smooth bottom as compared to the percentage of rough bottom. This examination showed that 37% of the sea floor crossed by the Expedition is smooth and 63% is rough. Inasmuch as the smooth regions occupy the topographic lows, it can be assumed that they are areas of sedimentary accumulation. In recent years coring from vessels equipped with echo sounders has tended to establish the principle that smooth bottom indicates unconsolidated sediment whereas rough bottom is generally rocky. Although sediment is encountered in the rough areas, it seems probable that it forms only patches or a thin cover supported by a " backbone " of bed rock. Thus, almost two thirds of the sea floor traversed on the Mid-Pacific Expedition may be rock only patchily covered with sediment.

Rough bottom especially characterized the first leg of the Expedition between the U.S. and Hawaii, although several small smooth basins were found near the U.S. These basins may be related to the shedding of sediment by the North American continental block. The filling of these basins is most evident near the continental slope and decreases to the west, suggesting such a directional source of the sediment. Another area of smooth bottom was found in the vicinity of Point A. This may be related to the high production and consequent rapid deposition of pelagic organisms beneath the Equatorial Counter Current. Between the Hawaiian Islands and Bikini extensive flat basins were found flanking the Mid-Pacific Mountains and between the large seamounts of this range. The discovery of this apparently extensive and deep fill of sediment was surprising inasmuch as the region is far removed from the continental blocks and the organic production in these water is small. It seems necessary to assume that this is a region where sediment has accumulated during an extremely long period of time without any rejuventation of the bottom topography by tectonism or extrusion of lava flows. The Cretaceous age (HAMILTON, 1952 ; 1953) of the Mid-Pacific Mountains tends to support this point of view and by contrast suggest a Cenozoic age for the rough unsmothered topography of the first leg.

On the return passage from Bikini to the U.S., rough bottom was found to characterize the Hawaiian Swell but some areas of smooth bottom were found between this swell and the Mendocino Escarpment. South of the Mendocino Escarpment, an extensive smooth basin was traversed about 400 miles west of San Franciso. From previous work (MENARD and DIETZ, 1951) it is known that the region of the Gulf

of Alaska north of this scarp also has an extensive smooth sea floor sloping to the southwest.

It is clear that there is little basis for the common assumption that the sea floor is a smooth featureless sedimentary plain upon which sediments everywhere accumulate at a uniform rate. Instead it appears that sea floor topography is determined largely by tectonic movements and volcanic extrusions. The principal role of sedimentation is to fill in the topographic lows. The localization of sedimentation in the basins and the apparent absence of a draped cover of sediments over all the sea floor topography makes it evident that horizontal transportation of sediments takes place along the bottom. Such movement along the bottom and the localization of deposition in basins must be taken into consideration by those who attempt to determine the rate of deposition in the deep sea as a whole by radioactive or other measurements on cores obtained from the sites of deposition.

ACKNOWLEDGMENTS

Although the writers had responsibility for the bathymetric programme on the Mid-Pacific Expedition, the entire scientific staff of both vessels participated in monitoring the echo sounders, recording the sounding data, and maintaining a corrected track plot. In particular, assistance by ROGER REVELLE, Expedition Leader, and by JEFFERY D. FRAUTSCHY and ROBERT F. DILL deserves special acknowledgement and is greatly appreciated by the writers. The writers were materially assisted in plotting and drafting by G. E. BRAYTON, SHIRLEY C. FISHER and GARRETT L. PRIBLE.

U.S. Navy Electronics Laboratory, San Diego, California, U.S.A.

(Professional Contribution of the Navy Electronics Laboratory, No. 31).

(Contribution of the Scripps Institution of Oceanography, No. 721).

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A new deep-sea winch

B. KULLENBERG and R. MICHAELSON

Summary—This article describes the manufacture and performance of a deep-sea winch which was fitted to the *Albatross* for use in the Swedish Deep-Sea Expedition, mainly for use in deep-sea coning.

WHEN the *Albatross*, the training-ship of the Broström shipping combine of Göteborg, was being fitted out as a temporary research vessel for the Swedish Deep-Sea Expedition 1947-48, a deep-sea winch had to be manufactured to meet very high demands, since its main purpose would be to serve at deep-sea coring. In its principal features the winch was designed as early as 1944, when the experience of modern heavy gears for deep-sea coring was still limited to Swedish coastal waters with a depth not exceeding 500 metres.

In the conventional trawl winch for deep-sea work the hauling power is exercised by the drum, which does not appear to be quite satisfactory when the tension in the cable is very high. When long cores are to be collected in deep water, the great weight of the corer makes the tension in the cable higher than during trawling, especially those stages of the trawling when the winch is running. Moreover, the tension variations caused by waves and swell are greater, owing to oscillations of the core and also to the fact that the cable takes on a rectilinear shape, whereas during trawling the curvature of the cable will largely smooth out tension variations. Finally, the tension in the cable may reach a very high value when the corer is pulled out of the bottom. It was believed that such high tension would expose the drum to an excessive strain and, further, that the cable would be unduly strained by being stored on the drum under very high tension. It was decided, therefore, that the hauling power should be exercised by a main winch with two parallel horizontal drums, as a principle working as two capstans, and that the cable coiling winch should be provided with a motor only sufficient for taking up the slack.

The prototype of the new winch was the deep-sea anchoring equipment of the *Meteor* (SPIESS 1932), a counterfeit of which was built on the *Willebrord Snellius* (PERKS 1938). Here the cable was paid out, and hauled in, by means of the anchor capstan, and it was wound on the cable drum at a low tension. However, if only one capstan is used the cable will move continually towards one end of it and the cable will slip back to the centre of the capstan with more or less heavy jerks. This would be most inconvenient at deep-sea corings since it would expose the cable to incessant twists and, further, the corer might become accidentally released during an early stage of the lowering, when such a release could be fatal to both cable and corer. It would also be impossible to run the capstan at a high velocity. The inconvenience can be avoided by using two capstans coupled together, because then the cable will remain stationary on both, particularly if the capstans are fitted with a number of grooves for the cable to run in.*

* It was Mr. AXEL JONASSON, the instrument-maker of the Oceanographic Institute in Göteborg, who suggested to us that the winch should be fitted with two capstans instead of one.

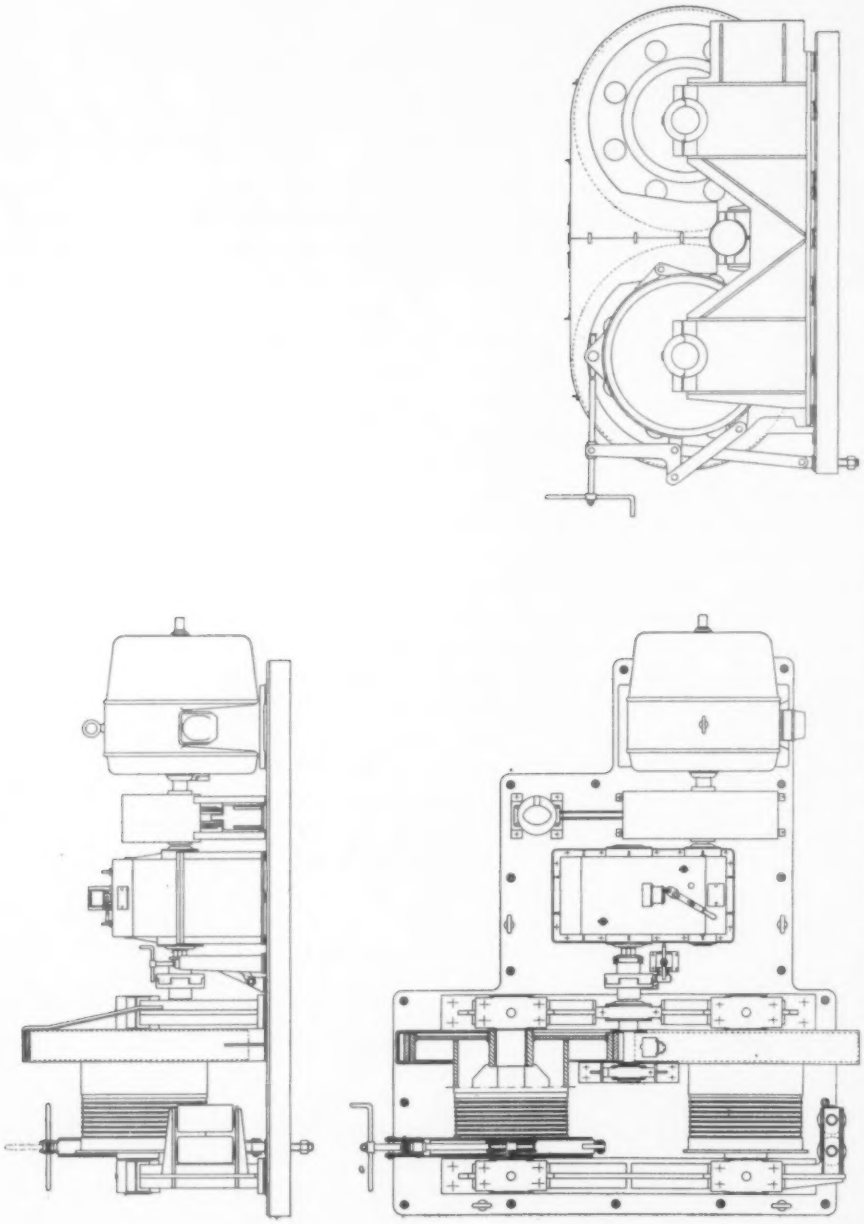

Fig. 1. The main winch with two grooved drums exercising the hauling power.

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The main winch is driven by an electric motor. The motor, a friction coupling with a magnetic brake, a gear box, and the two grooved drums are assembled on a welded steel bed plate (Fig. 1).

The motor is coupled to the primary shaft of the gear case by means of the friction coupling, the external rim of which serves as a brake disk for the magnetic brake. The primary shaft is fitted with a double pinion that can be moved in axial direction so as to drive one of the two pinions on the secondary shaft. The gear ratios are as 2 to 1. The secondary shaft is coupled to the main gear driving the drums by a claw coupling that can be released. The gear ratio in this transmission is 7·8, and the total gear ratio between motor and main winch is 45·2 or 22·6, depending on the adjustment of the gear case. With a view to sparing the cable, the diameters of the drums are as large as 800 mm. There are eight grooves for the cable in each drum though, as a rule, it is not necessary to use more than five of them.

The magnetic brake will operate as soon as the field winding of the motor is currentless. One of the drums is fitted with a screw brake which may be used to diminish the torque exerted on the motor during the lowering when much cable has been paid out, or to secure the drums when the gear is adjusted. The screw brake is, further, used to diminish the velocity when lowering is performed with the drums disconnected from the motor by disengaging the claw coupling.

Cable coiling barrel, electric motor, friction coupling with magnetic brake, gear case, and cable guide are assembled on a welded steel bed plate (Fig. 2).

The cable coiling winch is driven by a 9 kW motor coupled to the barrel in the same way as has been described above for the main winch and its motor. As in the case of the main winch the gear can be adjusted for two speeds with the ratio 2 : 1, and as the barrel must be run with the same speed as the main winch the couplings are blocked electrically so as to make it impossible to start the motors unless both gears are adjusted in the same way. The cable guide can be adjusted for six cable diameters, viz. by steps of 2 mms from 12 to 22 mm. The barrel is 800 mm in diameter and 2,200 mm between flanges, and the diameter of the flanges is 1,600 mm; it can store 12,000 m cable tapered from 12 to 22 mm in diameter. The barrel is fitted with a screw brake.

Both winches have bed plates, bearing brackets, barrels and brake equipments of welded design. In all gears the pinions are of special forged steel, the smaller wheels of cast steel and the bigger ones with rims of forged steel shrunk on welded centres. All gears have machine cut teeth.

The current to the motor driving the grooved drums is furnished by a dynamo with a tension of 230 v and an effect of 130 h.p. at 550 r.p.m., which is driven by a Diesel engine with an effect of 200 h.p. at 550 r.p.m. The dynamo is connected to the motor by a Ward-Leonard coupling. The source of current for the motor driving the cable drum is a motor converter fitted with a direct current machine.

In the motor of the main winch the field winding is connected to a constant line voltage, so the direction and speed of the motor is determined by the sign and magnitude of the voltage furnished by the dynamo. The sign of the voltage may be changed by means of a reverser, and its magnitude is adjusted by means of a resistance connected to the field winding of the dynamo. When the tension has reached its maximum value, the speed of the motor may be further increased by diminishing the current in its field winding by cutting in a resistance.

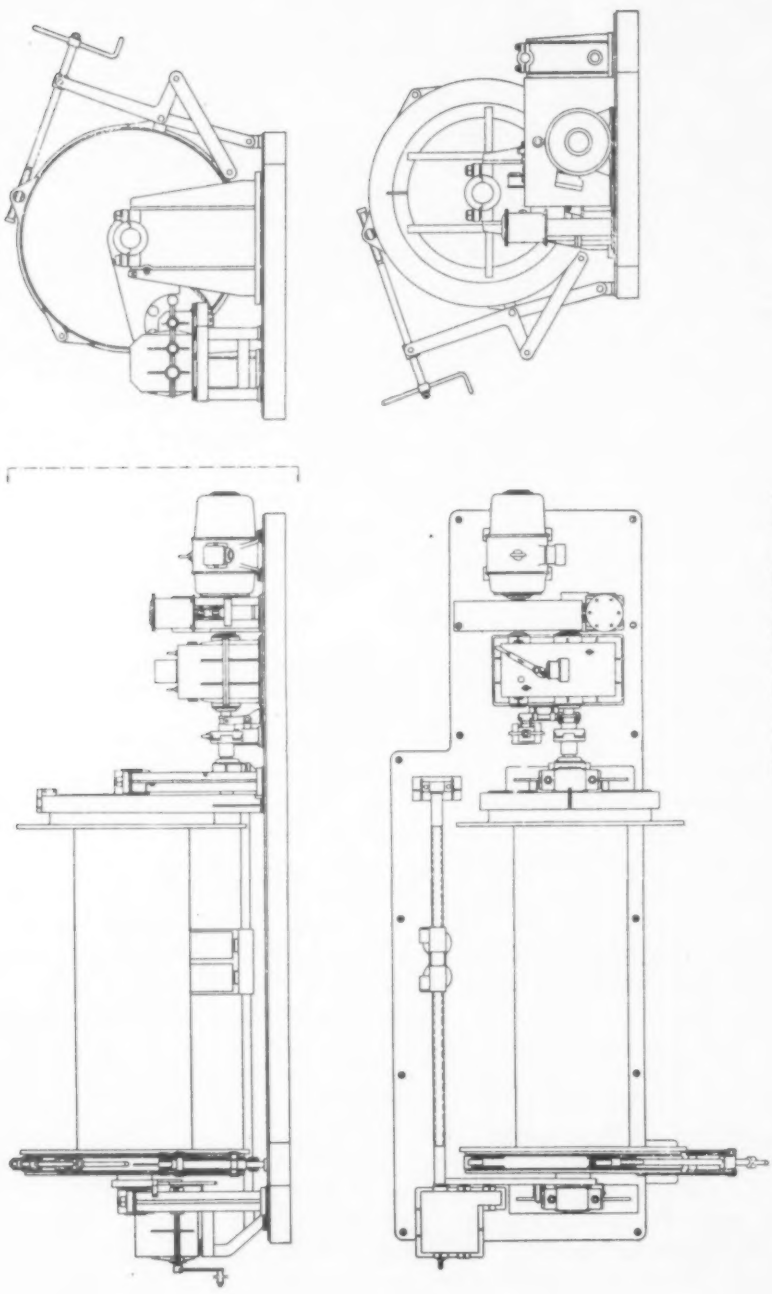

Fig. 2. The cable coiling winch.

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During the lowering of the corer the motor will function as a dynamo when so much cable has been paid out that the tension in the cable is sufficiently high enough to drive the winch against the friction. The dynamo will then run as a motor and drive the Diesel engine. In view of the losses in the machinery only a minor part of the effect furnished by corer and cable has to be consumed by cutting in an adequate resistance. If necessary, part of the effect may be removed by means of the screw brakes.

The maximum hauling power of the winch is 12,000 k.g.p., and the maximum speed is 114 m/min. The great gear ratio may always be used during lowering, but during hauling the small gear ratio should be used when the tension in the cable exceeds 3,000 k.g.p. With the small gear ratio the maximum speed is 80 m/min.

At a deep-sea coring with the piston corer it is essential to be able to stop the winch almost instantaneously when the corer has reached the bottom. The winch described here may be stopped abruptly, even when run at a high speed, by switching off the current in the field windings, in which case the magnetic brakes are brought into immediate action; this is done by pressing either of two buttons, one of which is situated on the main deck near the dynamometer, giving the tension in the cable, with a view to enable the leader of the coring to stop the winch himself without having to shout an order.

On board the *Albatross* the winch was placed in Hold No. 1. The cable was conducted from the barrel to the grooved drums by a horizontal sheeve. Between this one and the barrel there was inserted an accumulator giving a certain amount of play to the cable. This is necessary in view of the difficulty to keep the cable tight between the main winch and the cable coiling winch, especially when the speed is being reduced during lowering, or increased during hauling. If the cable is allowed to get slack between the two winches, it will be spoiled by kinking.

When a tapered rope is hauled in certain precautions are necessary. This is at the time when the capstans are passed by one of the junctions where the diameter of the cable is reduced to a lower value. The thicker part of the cable is running in at a certain speed, and the thinner portion of the cable follows at a slightly lower speed. This may increase the tension in the junction considerably and may ultimately cause the cable to break. If the critical portions of the cable are lubricated thoroughly, the cable will escape injury by sliding on the grooved drums which will eliminate the lengthening of the junction brought about by the different speeds of the cable at each end. This is facilitated by making the tension in the cable very small between the two winches, which it is possible to do without slackening off the cable, thanks to the accumulator mentioned before. Further, the sliding of the cable may be facilitated by making the cable very taut between the grooved drums by means of a wooden lever and then releasing it suddenly, and repeating this continually until the critical part of the cable has left the grooved drums. In any case, the winch should be run at a low speed when a junction in the cable is being hauled in.

This winch behaved in a most satisfactory way during the Swedish Deep-Sea Expedition 1947-48. In 1950 it was transferred to the Danish research vessel the *Galathea* and served as a trawl-winch during the circumnavigating cruise of the *Galathea* on its record trawlings down to the bottom of the Philippine Trench (10,400 m). Although, on the *Galathea*, a weaker motor was substituted for the

original one driving the main winch, which lowered the strength and speed of the winch, it aquitted itself very well.

The complete deep-sea winch (main winch and cable coiling winch) was designed by ASEA, Västerås, and this firm also supplied the electrical equipment. The mechanical parts were built in the NOHAB works at Trollhättan according to ASEA's specification.

Oceanografiska Institutet, Göteborg, and ASEA, Västerås.

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LETTERS TO THE EDITORS

A correlation between the oxygen content of sea water and the organic content of marine sediments*

THERE is considerable opinion but little direct evidence that the oxygen content of overlying water masses is important in determining the organic content of marine sediments (CORRENS 1939 ; FLEMING and REVELLE 1939).

CORRENS (1939) noted a very general inverse relationship in the *Meteor* observations, and concluded that the high oxygen content of the Atlantic deep water was not favourable to the preservation of the organic matter in the sediments. On the other hand, he stated in 1937 " Vergleicht man nun die Sauerstoffwerte des Tiefenwassers ..... mit dem Humusgehalt der Sedimente, so findet man keine Parallelität." KUENEN (1942) found no direct correlations between these variables in the Dutch East Indies.

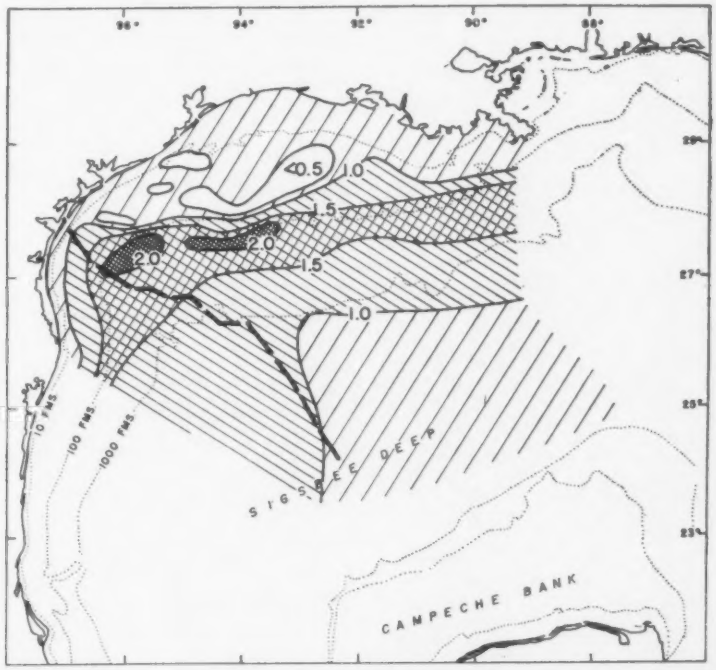

Fig. 1. Organic content of surface sediments. Numbers represent percent of organic matter, estimated as 1·8 times the carbon content. From Trask (8). Heavy dashed line shows line of stations used for comparison with bottom oxygen content in Fig. 2.

Data now available from the northwestern Gulf of Mexico indicate a clear-cut inverse relationship between the organic content of the sediments and the oxygen content of the overlying waters. TRASK (1953) has reported on the organic content of sediments, and oxygen was determined during a cruise of the *Atlantis* in 1935 (Bulletin Hydrographique). TRASK found maximum organic matter in sediments at depths of 150 to 850 metres, and minimum concentrations of oxygen (less than 3·0 ml/l) were found overlying the bottom at these same depths. The zones of maximum organic content

*Contribution No. 695 from the Woods Hole Oceanographic Institution.

and minimum oxygen correspond well, and closely follow the edge of the Continental Shelf (Fig. 1 and overlay).

Two lines of stations from each of these cruises lay close enough together that the organic nitrogen and noncarbonate carbon content of the sediments can be compared with the oxygen content of the water over the bottom, estimated by extrapolating the station data (Fig. 2). The maxima in nitrogen and carbon coincide closely with the oxygen minima, and an inverse relationship holds both below and above the oxygen minimum layer. It can be concluded that the highest organic content is found in the zone where the oxygen minimum layer impinges on the bottom.

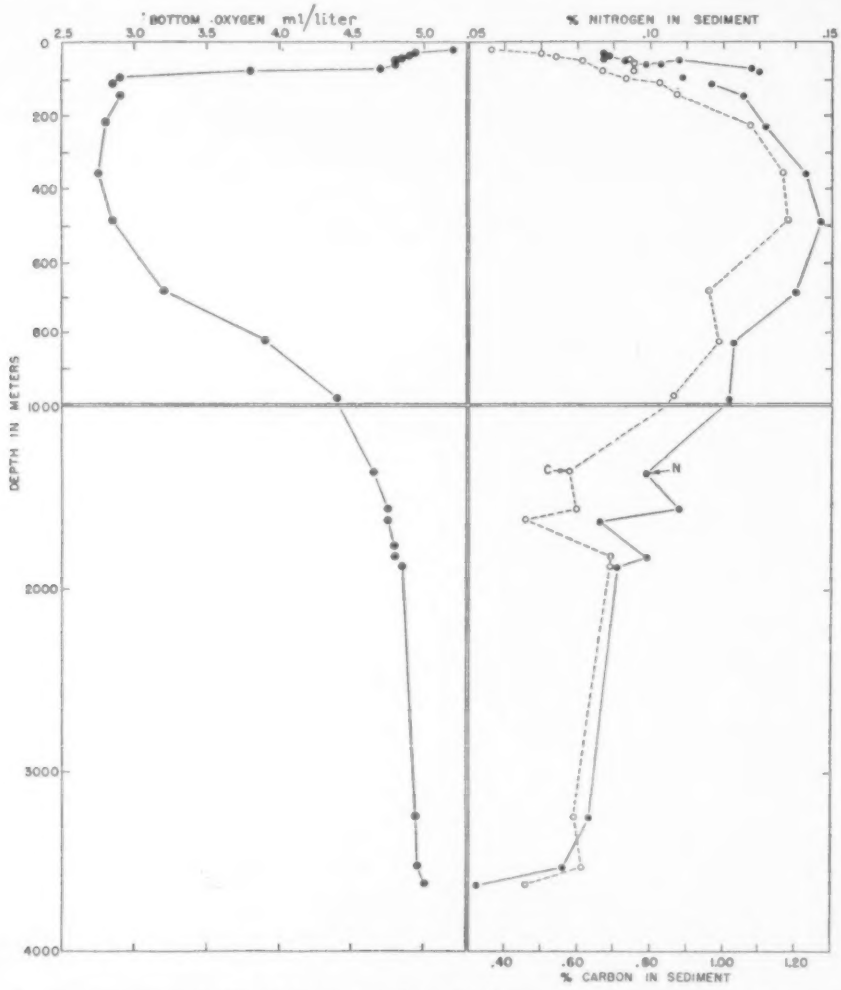

Fig. 2. Oxygen content (ml/litre) of water overlying the bottom and non-carbonate carbon content (%) and nitrogen content (%) of sediments along the lines of stations shown in Fig. 1 and overlay. Nitrogen estimated in surface layer of sediments, carbon estimated in layer approximately 25-35- cm. below the surface.

It may be predicted, from the oxygen distribution, that sediments rich in organic material will be found continuing northeastward from those reported by TRASK (Fig. 1), and along the edge of the Campeche Bank.

High organic content is equivalent to high oxygen demand, and so contact with organic-rich bottom sediments might be held responsible for the oxygen minimum. Such a mechanism was proposed by THOMPSON, THOMAS and BARNES (1934), and may cause the oxygen minimum layer which was observed off fjords by THOMPSON and BARKEY (1938). However, in the Gulf of Mexico, the oxygen minimum layer is presumably of more remote origin, representing waters de-oxygentated in the Atlantic Ocean. It is probable that in this region, the high organic content of the sediments is due to the presence of water of low oxygen content immediately above the bottom, and the smaller oxygen diffusion gradient available to provide oxygen to the subsurface layers of sediment.

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts FRANCIS A. RICHARDS
ALFRED C. REDFIELD

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Electrical lead-through plugs

SHUMWAY (1954) in considering the problems associated with carrying electrical conductors through water tight cases for deep sea apparatus, has stressed the difficulties associated with the use of standard packing glands. The difficulties are even greater when it is required to use cable sheathed with P.V.C. since this follows markedly under pressure. Apart, therefore, from ineffective sealing there

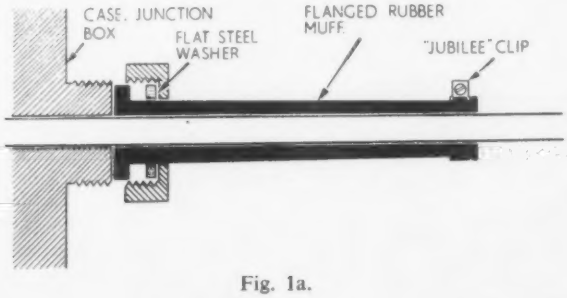

Fig. 1a.

is a very great danger of damaging the fine conductors in a multi-core cable. He describes two types of lead-through plugs in both of which rubber is moulded round the end of the plug and the moulded rubber bonded to plastic and the projecting end of the insulated brass rod serves as the conductor.

A similar type of lead-through was considered in our underwater television work. Apart from the difficulties associated with multi-core cables the method suffers from the disadvantage that, if there is any break of the moulded part, repairs are not easily effected at sea – indeed the whole cable must be returned for a new moulding.

We have used the method described below both for entry of multi-core television cables and for simpler electrical leads on a number of units. It was developed for us by British Insulated Cables Ltd. The method has proved very satisfactory to depths of up to 100 fathoms ; we have had no opportunity of tests at greater pressures. Since it may easily be adapted to existing apparatus the following description may be of use to other workers in this field.

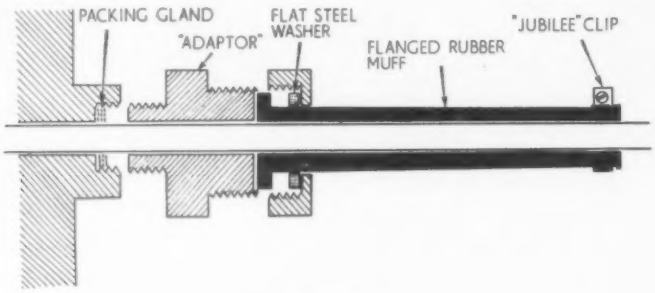

Fig. 1b.

The cable is passed through a moulded rubber muff (Fig. 1a) and via a screwed head into the water tight container, or, if required, into a separate junction box which is fastened to the container using a conventional gasket. The flanged end of the muff seats on to the face of the screwed head which may be hollowed to take the flange. It is clamped down by a screw nut and flat steel washer. At the outer end of the muff a simple "Jubilee" clip is fastened tightly round the muff and cable. Fig. 1b shows the same principle, but here the cable passes through an adaptor fitted to the existing apparatus : the screwed adaptor is then seated on the apparatus by a conventional packing gland.

The Marine Station,
Millport, Scotland.
May 18th, 1954.

H. BARNES
A. G. RANDALL

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NOTICE OF MEETINGS

Joint Commission on Oceanography

A MEETING of the Joint Commission on Oceanography of the International Council of Scientific Unions will be held in Rome on September 13th and 14th. The main item on the agenda is likely to be the desirability of the establishment of a Deep-Sea Council to deal with most questions internationally which concern expeditions and research on the deep-sea floor.

International Committee on the Nomenclature of Ocean Bottom Features

A MEETING of this Committee will be held at Monaco at the International Hydrographic Bureau on September 9th and 10th under the Chairmanship of DR. J. D. H. WISEMAN.

ANNOUNCEMENTS

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Dedication of the Laboratory of Oceanography and Oceanographic Convocation

On Monday, the twenty-first of June, the new Laboratory of Oceanography at Woods Hole was dedicated by the Office of Naval Research with appropriate ceremonies and was reassigned to the Woods Hole Oceanographic Institution for operation. This was followed by a three-day Oceanographic Convocation sponsored by the Office of Naval Research, the National Academy of Sciences, the National Research Council, the Marine Biological Laboratory, the Woods Hole Oceanographic Institution and the Fish and Wild Life Service. The convocation programme was as follows :—

Chairman, *pro tem.*
Rear Admiral EDWARD H. SMITH, U.S.C.G. (Ret.) Director, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Welcoming Address
Rear Admiral F. R. FURTH, U.S.N., Chief of Naval Research

Tuesday, June 22nd, 1954

Discussion of Physical Oceanography

Morning Session

Chairman,
Dr. H. U. SVERDRUP, Norsk Polarinstitutt, Oslo, Norway

Speakers : DR. H. U. SVERDRUP, Norsk Polarinstitutt, Oslo, Norway.
Dr. CARL ECKART, Scripps Institution of Oceanography, La Jolla, California.
Dr. WALTER H. MUNK, Scripps Institution of Oceanography, La Jolla, California.

Afternoon Session

Chairman,
Captain J. B. COCHRAN, U.S.N., Hydrographer, United States Navy

Speakers : Dr. C. O'D. ISELIN, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.
Dr. JOHN D. ISAACS, Scripps Institution of Oceanography, La Jolla, California.
Dr. G. E. R. DEACON, Director, National Institute of Oceanography, Surrey, England.
Dr. RICHARD H. FLEMING, University of Washington, Seattle, Washington.

Evening Lecture

Speaker : Dr. G. E. HUTCHINSON, Yale University, New Haven, Connecticut.

Wednesday, June 23rd, 1954

Discussion of Biological Oceanography

Morning Session

Chairman,

Professor TRYGVE BRAARUD, Universitets Biologiske Laboratorium, Oslo, Norway.

Speakers : Dr. DETLEV W. BRONK, President, National Academy of Sciences—National Research Council.
Dr. L. H. N. COOPER, Marine Biology Laboratory, Plymouth, England.
Professor L. R. BLINKS, Hopkins Marine Station, Pacific Grove, California.
Professor E. STEEMAN NIELSEN, Danmarks Farmaceutiske Høskole, Copenhagen, Denmark.

Afternoon Session

Chairman,

Dr. HENRY B. BIGELOW, Harvard University, Cambridge, Massachusetts

Speakers : Dr. GUNNAR THORSEN, Zoologiske Museum, Copenhagen, Denmark.
Mr. O. E. SETTE, Director, Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu, T.H.
Dr. GEORGE WALD, Harvard University, Cambridge, Massachusetts.

Thursday, June 24th, 1954

Discussion of Geology and Geophysics in Oceanography

Morning Session

Speakers : Professor MAURICE EWING, Lamont Geological Observatory, Palisades, New York.
Dr. HARRY H. HESS, Princeton University, Princeton, New Jersey.
Dr. P. H. KUENEN, Geologische Institutt, Groningen, Netherlands.
Dr. ROGER REVELLE, Scripps Institution of Oceanography, La Jolla, California.

Discussion of Meteorology in Oceanography

Afternoon Session

Chairman,

Dean ATHELSTAN F. SPILHAUS, Institute of Techonology, University of Minnesota, Minneapolis, Minnesota

Speaker : Dr. C. G. ROSSBY, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

This is thus the fourth laboratory in the small village of Woods Hole. The others are : the Woods Hole Laboratory of the Fish and Wildlife Service, the Marine Biological Laboratory and the Woods Hole Oceanographic Institution.

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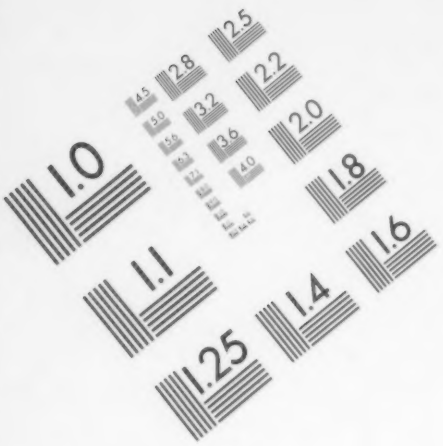

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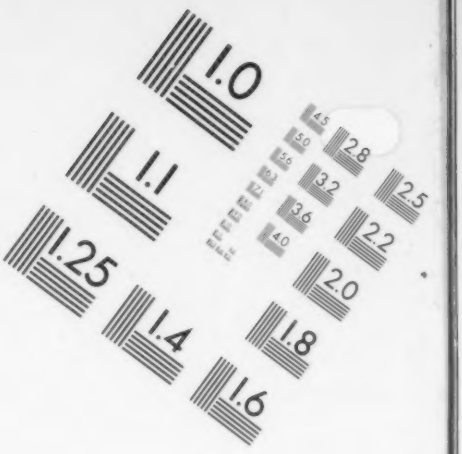

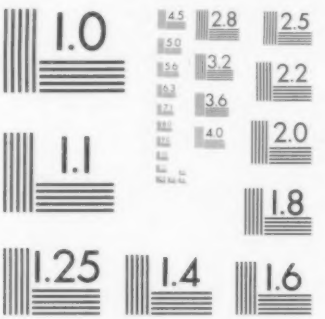

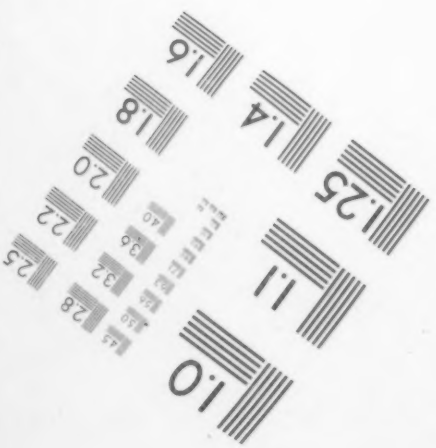

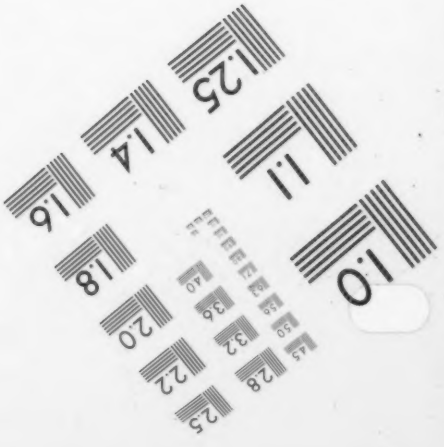

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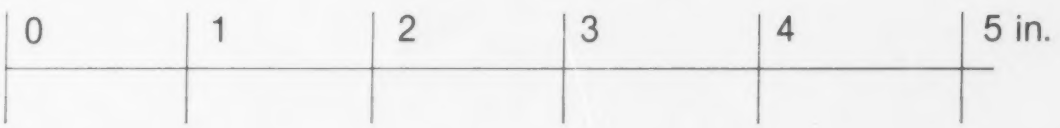

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